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COMMERCIAL FERTILIZERS:

COMPOSITION AND USE.

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COMMERCIAL FERTILIZERS.

There is, perhaps, no question of greater importance to the practical farmer than that of soil fertility. To produce profitable crops and at the same time to maintain and even to increase the productive capacity of the soil may rightly be termed "good farming." Many farmers are able to do this, and the knowledge of *how* to do it has been largely acquired through years of experience, during which the character of the soil, its adaptability for crops, and the methods of its management and manuring have been made the subjects of careful study, without, however, any definite and accurate knowledge concerning manures and their functions in relation to soils and crops. Experience is an excellent teacher; still, a definite knowledge of first principles may be substituted for years of experience in the successful use of manures.

THE NEED OF COMMERCIAL FERTILIZERS.

The fertility of the soil would remain practically unchanged if all the ingredients removed in the various farm products were restored to the land. This is to a large extent accomplished by feeding the crops grown on the farm to animals, carefully saving the manure and returning it to the soil, and if it is practicable to pursue a system of stock feeding in which those products of the farm which are comparatively poor in fertilizing constituents are exchanged in the market for feeding stuffs of high fertilizing value the loss of soil fertility may be reduced to a minimum or there may be an actual gain in fertility.

The following table, showing the amounts of fertilizing constituents in 1 ton of different agricultural products, indicates directions in which such an exchange may be effected with advantage:

Manurial constituents contained in 1 ton of various farm products.

	Nitrogen.	Phosphoric acid.	Potash.
	Pounds.	*Pounds.*	*Pounds.*
Meadow hay	20.42	8.2	26.4
Clover hay	40.16	11.2	36.6
Potatoes	7.01	3.2	11.4
Wheat bran	49.15	54.6	28.6
Linseed meal	105.12	32.2	24.8
Cotton-seed meal	135.65	56.2	29.2
Wheat	37.53	15.8	10.6
Oats	36.42	12.4	8.8
Corn	33.06	11.8	7.4
Barley	39.65	15.4	9.0
Milk	10.20	3.4	3.0
Cheese	90.60	23.0	5.0
Live cattle	53.20	37.2	3.4

The exchange of 1 ton of corn for 1 ton of wheat bran, for instance, will result in a gain of 16 pounds of nitrogen, 43 of phosphoric acid, and 21 of potash. With an exchange of milk or potatoes for the concentrated feeding stuffs the gain is still more striking.

A careful study of the present condition of farming in the United States indicates, however, that as a rule the manure produced on the farm is not sufficient to maintain its fertility and that the need for artificial supplies is real, though the amount required may be considerably reduced by careful management.

In the system of so-called "grain farming" which has obtained over large areas of this country for a long time, and is still practiced in the Eastern, Middle, and Central Western States, the live stock kept is often limited to a number sufficient only to the needs of the farm for labor and food; the grain is sold, and the manure is made up chiefly of the natural wastes, or unsalable material, such as straw, stalks, etc. The grain contains proportionately greater amounts of nitrogen and mineral constituents than these wastes; hence the practice continued for a long time results not only in a deficiency in the soil of organic substances containing nitrogen, but also in an exhaustion of the mineral substances. The original character of the soil and its treatment measure the rate of exhaustion. The less fertile soils of the East and South are rapidly depleted, while the rich prairie and river bottoms maintain their fertility for a longer period.

Special crop farming, as for example the continuous cotton and tobacco growing of the South and the wheat growing of the West, is even more exhaustive, since here the demands upon the soil are not changed—year after year the same crop is grown and the same kind and proportion of constituents are required, while even less returns are made in the way of manure than in the system of farming above described. Moreover, the land is left bare for a large part of the year and loss of fertility from this cause is very large. The crops are less abundant each year, not because the soil is entirely exhausted, but because it is so far exhausted of those constituents essential to the special crop grown that its production is no longer profitable.

Changed conditions of farming, which have an important bearing on this point, may be observed in two directions—(1) in the increased cost of labor and in the lower prices of grain, cotton, and tobacco; and (2) in the increasing demand for market garden products and fruit. For example, in growing wheat, the labor of preparing the soil, of cultivation, and of harvesting is practically the same whether the yield is 10 bushels per acre or 30 bushels. The same is true of a number of other crops; hence in the larger yield the cost of labor per bushel is materially reduced; meager crops of a relatively low value can not be produced profitably with high-priced labor. Soils of a high degree of fertility are required in order to produce large yields of these crops. The return to the soil of only the wastes of the farm results sooner or

later in a decrease in fertility, however good the management may be; hence the need of supplies of plant food from sources outside the farm in order that maximum crops may be produced.

In the case of market garden crops, it has been proven that even very fertile soils contain too little available food to insure a maximum production; this is especially true where rapidity of growth, earliness, and high quality of produce are important factors. The areas now necessarily devoted to these crops are so great that the amount of farm manures available is much too small; besides, the constituents contained in such manures, being slowly available, are less useful than the more active forms contained in commercial fertilizing materials. They are in a sense artificial crops and, as a rule, need artificial supplies of plant food.

Fruit culture, an industry of growing importance, is profitable, particularly on the poorer soils near the Eastern markets, largely in proportion to the supply of the mineral elements in excess of those contained in soils otherwise well adapted to the crops. A sufficiency of food not only enables the trees to resist unfavorable conditions, but improves the quality of the fruit and extends the bearing period of the orchards and vineyards.

It will thus be seen that it is either to make up the deficiencies of farm manures or in specialized intensive farming that commercial fertilizers can be most advantageously used. The latter should supplement and not entirely replace the manurial resources of the farm. They give best results as a rule on soils well stocked with organic matter (humus), a material which can be maintained in soil only by the regular application of the bulky farm manures (including green manures).[1]

FERTILIZER REQUIREMENTS OF DIFFERENT SOILS AND CROPS.

Nitrogen, phosphoric acid, and potash are the constituents most likely to be deficient in soils or most quickly exhausted by the production and removal of crops. These are known as "essential" fertilizing constituents, and the value of a commercial fertilizer is determined almost exclusively by the amount and form of the nitrogen, phosphoric acid, and potash which it contains. It does not follow, however, that all soils or crops will respond equally to applications of materials containing these elements, because the needs of soils and the requirements of crops vary.

Soils differ in respect to their needs for specific elements, owing either to their method of formation or to their management and cropping. A sandy soil is usually deficient in all the essential plant-food constituents—nitrogen, phosphoric acid, and potash—while a clayey soil usually contains the mineral elements in abundance, particularly potash. On the other hand, a soil very rich in vegetable matter is frequently

[1] See Farmers' Buls. 16 and 21 of this Department.

deficient in mineral matter, while a limestone soil is likely to contain considerable proportions of phosphoric acid. These are the indications in a general way, and they explain why it is that different kinds of soil that have not been cropped differ in respect to their needs in reference to the different fertilizing constituents.

Methods of management and cropping also exert an influence; for example, soils of equal natural fertility may not respond equally to uniform methods of fertilization, because in the one case a single crop, requiring for its growth proportionately more of one of the essential elements than of another, is grown year after year, and it may be that the element required is the one that exists in the soil in least quantity. On the other hand, crops may be grown that demand but minimum amounts of the element in question; hence its application to the soil for the one crop may be followed by largely increased returns, while for the other but little if any increase in crop is apparent.

In the matter of management, too, a considerable variation may be observed. One soil may lose a large portion of its essential constituents, because no pains are taken to retain for the use of the crop the constituents annually rendered available through the natural agencies of sun, air, and water; while in another, by means of careful cultivation and the use of absorbents and catch crops, the constituents made available are largely retained.

Crops differ in respect to their power of acquiring food.—The legumes, a class of plants which includes the various clovers, peas, beans, vetches, etc., differ from other plants in being able, under proper conditions, to acquire their nitrogen from the air, and can, therefore, make perfect growth without depending upon soil nitrogen. On the other hand, the various grasses and grains are not only dependent upon soil nitrogen, but they must have an abundance during their most rapid period of growth in order to attain their maximum development. For the latter class of plants favorable results are secured from the proper use of nitrogenous manures, while for the former class the application of nitrogenous manures simply results in supplying an element which could have been secured quite as well by the plant itself, without expense. Illustrations could be multiplied, though perhaps less striking than this, showing that the variations in crops in respect to their power of acquiring food are really very great, and a right knowledge of this fact has a most important bearing upon the economical use of commercial manures.

"The most satisfactory, and, indeed, usually the only method," says Armsby, "by which we can at present determine the needs of a soil is to ask the question of the soil itself by growing a crop upon it with different kinds of fertilizers and noting the result. Such soil tests with fertilizers have in many cases given results of much immediate practical value for the locality in which they were undertaken. As a rule, however, farmers have looked upon such experiments as something too

costly and complicated for them to undertake, and consequently they have perforce been content to use fertilizers in a more or less haphazard manner, and in many cases, no doubt, at a great financial disadvantage."

While such tests are not so difficult or expensive as is often supposed, it is recommended that before the farmer undertakes them for the first time he seek the advice of someone familiar with the details of such work, or, preferably, apply to the experiment station of his State.

FORMS, SOURCES, AND COMPOSITION OF FERTILIZING MATERIALS.

The term "form" as applied to a fertilizing constituent has reference to its combination or association with other constituents, which may be useful, though not necessarily so. The form of the constituent, too, has an important bearing upon its availability, and hence upon its usefulness as plant food. Many materials containing the essential elements are practically worthless as sources of plant food because the form is not right; the plants are unable to extract them from their combinations; they are "unavailable." In many of these materials the forms are changed by proper treatment, in which case they become valuable not because the element itself is changed, but because it then exists in such form as readily to feed the plant.

NITROGEN.

Nitrogen is the most expensive of the three essential fertilizing elements. It exists in three distinct forms, viz, as organic matter, as ammonia, and as nitrate.

Organic nitrogen exists in combination with other elements either as vegetable or animal matter. In fact all plants and animals contain nitrogen in this form, and the relative value of the various substances as sources of nitrogen depends upon their content of it and upon the character of the substance and its treatment. All materials containing organic nitrogen are valuable in proportion to their rapidity of decay or change, because decay and change of form must take place before the nitrogen can serve as food. In some cases the decay is longer delayed than in others. The material may be hard and dense, or it may have been treated for the express purpose of preventing decay, or it may be associated with other substances that resist the agents which effect decay. Thus organic nitrogen differs in availability not only according to the kind of material which supplies it, but upon the treatment it receives.

The most abundant supplies of nitrogen occur in organic forms. The most valuable sources of organic nitrogen, from the standpoints of uniformity in composition, richness in the constituent, and availability, are dried blood, dried meat, or azotine, and concentrated tankage, which are produced in large quantities in slaughterhouses and rendering

establishments; dried fish, refuse from fish-oil and canning establishments; and cotton-seed meal, the residue of the cotton seed after the oil has been extracted. These vary somewhat in composition, but within comparatively narrow limits (see table, p. 25). They are all rich in nitrogen, and decay rapidly when the conditions are favorable, and are very useful in cases where rapid and continuous feeding of the plant with nitrogen is desirable.

These products, while valued principally as sources of nitrogen, also furnish more or less phosphoric acid, the dried blood and meat showing the least and the fish the greatest amount. Other nitrogenous materials which are less desirable are leather meal, horn and hoof meal, wool waste, felt waste, and similar products. These contain, as a rule, a high content of nitrogen, but they are so very slow to decay that it is doubtful whether their use in their original form is advisable when forms of known value are available at reasonable prices. Where the object is gradually to increase the fertility of the soil rather than to secure immediate returns, they may become useful. Farmers frequently have access to local supplies at a slight cost, the chief expense being the labor of carting and distributing, in which case they are worth considering.

Nitrogen as ammonia exists in commercial manure products in the form of sulphate of ammonia, chlorid of ammonia, etc., and is more readily available than organic forms. It is one of the first products that results from the decay of organic substances.

Nitrogen in the form of ammonia is obtained almost entirely from sulphate of ammonia, which is one of the most concentrated materials from which nitrogen is obtained for fertilizing purposes, the commercial product containing on the average 20 per cent of nitrogen. As already indicated, ammonia is one of the first products in the decay of organic substances, and this, together with the fact of its concentration, makes the sulphate an extremely valuable form of nitrogen. While it is extremely soluble in water, it is not readily removed from the soil by leaching, except in the absence of growing plants, since it is readily absorbed by organic and other compounds of the soil.

Nitrogen as nitrate exists in commercial products as nitrate of soda, nitrate of potash, etc. These, like the ammonia compounds, are extremely soluble, and the nitrogen contained in them is readily available as food for plants. The nitrogen in this form is directly and immediately available, no further changes being necessary.

The chief source of nitrogen as nitrate is nitrate of soda. This salt is rich in nitrogen, showing on the average 16 per cent, and is quite uniform in composition. It is completely soluble in water, diffuses readily throughout the soil, and differs from the ammonia compounds in forming no insoluble compounds with soil constituents. It is, therefore, liable to be washed out of the soil if applied in too large quantities or when there is an absence of vegetation. Plants that derive

their nitrogen from the soil secure it chiefly in the form of a nitrate; hence nitrate of soda is one of the most directly useful of the nitrogenous materials.

As already explained, nitrogen in organic forms is changed into ammonia by the decay or rotting of the substance. Ammonia, while it may nourish plants directly, is usually changed into a nitrate, in which form it is taken up by the plant. An application of nitrogen as nitrates may be completely used by the plant in a very short time; as ammonia or organic matter it may be partially or wholly used in the course of a season, depending upon whether the conditions are favorable for causing the changes that must take place.

PHOSPHORIC ACID.

Phosphoric acid is derived from materials called phosphates, in which it may exist in combination with lime, iron, or alumina as phosphates of lime, iron, or alumina. Phosphate of lime, however, is the form most largely used as a source of phosphoric acid. Phosphoric acid occurs in fertilizers in three forms: That soluble in water and readily taken up by plants; that insoluble in water, but still readily used by plants, also known as "reverted;" and that soluble only in strong acids and consequently very slowly used by the plant. The soluble and "reverted" together constitute the "available" phosphoric acid. The phosphoric acid in natural or untreated phosphates is insoluble in water and not readily available to plants; that is, the rate of availability depends largely upon the rapidity with which the substance rots or decays, and the rate of decay again depends upon the character of the substance with which the phosphate is associated. If it is combined with organic substance, as in animal bone, the rate of decay is more rapid than if with purely mineral substances. The insoluble phosphates are converted into soluble forms by treatment with strong acids, as explained later. Such products are known as acid phosphates or superphosphates.

Bone, in its various forms, is the only one of the insoluble phosphates that is now used directly upon the soil, or without other change than is accomplished by mechanical action or grinding. The terms used to indicate the character of the bone have reference rather to their mechanical form than to the relative availability of the phosphoric acid contained in them. The terms "raw bone," "fine bone," "boiled and steamed bone," etc., are used to indicate methods of preparation, and inasmuch as bone is a material which is useful largely in proportion to its rate of decay, its fineness has an important bearing upon availability, since the finer the bone the more surface is exposed for the action of those forces which cause decay or solution, and the quicker will the constituents become available. In the process of boiling or steaming, not only is bone made finer, but its physical character in other respects is also changed, the particles, whether fine or coarse,

being made soft and crumbly rather than dense or hard; hence it is more likely to act quickly than if the same degree of fineness be obtained by simple grinding. The phosphoric acid in fine steamed bone may all become available in one or two years, while the coarser fatty raw bone sometimes resists final decay for three or four years, or even longer. Bone, however, contains considerable nitrogen, a fact which should be remembered in its use, particularly if used in comparison with other phosphatic materials which do not contain this element.

Pure raw bone contains on an average 22 per cent of phosphoric acid and 4 per cent of nitrogen. By steaming or boiling, a portion of the organic substance containing nitrogen is extracted, which has the effect of proportionately increasing the phosphoric acid in the product; hence a steamed bone may contain as high as 28 per cent of phosphoric acid and as low as 1 per cent of nitrogen. Steamed bone is usually, therefore, much richer in phosphoric acid than raw bone.

Tankage is a bone product which, as a rule, contains more nitrogen than bone proper. It is also more variable in its composition, depending upon the proportions of bone and meat used in its preparation. It is not so largely used as a direct fertilizer as bone.

Other phosphates derived from bone, as boneblack, bone ash, etc., are but little used directly as sources of phosphoric acid; for while they are derived from organic sources, the treatment which they have received, besides depriving them of their nitrogen, causes them to be a much less valuable source of phosphoric acid than the various forms of bone already discussed. In both cases the organic substances which show the greater tendency to decay have been removed—in the case of boneblack by heating the bone in air-tight vessels, and in bone ash by burning in the open air.

The mineral phosphates differ from what may be termed "organic phosphates" in that they contain no organic or animal matter, and that they are more compact and dense in their nature. The chief sources of these phosphates are the river and land phosphates of South Carolina, the "soft," "pebble," and "rock" or "bowlder" phosphates of Florida, the "apatites" of Canada, the phosphate mines of Tennessee, and phosphatic slag,[1] a waste product from the manufacture of steel from phosphatic iron ores. With the exception of the latter, which is not an abundant product in this country, these phosphates are not yet used to any considerable extent, even when very finely ground[2] without having been treated with acid. They are, however, the chief raw materials from which superphosphates are made.

Superphosphates, or soluble phosphates, are derived from the insoluble materials already described by first grinding to a powder and

[1] Also known as Thomas Phosphate Powder, Thomas slag, and Odorless Phosphate.

[2] Finely ground mineral phosphate known as "floats" has been used to a limited extent in some localities.

then mixing with sulphuric acid, which changes the insoluble phosphoric acid to the soluble form. The soluble phosphoric acid thus obtained is a definite chemical compound, and is identical in composition whatever may have been the material from which it was derived. The term superphosphate is, therefore, applied to any material containing soluble phosphoric acid as its chief constituent. In superphosphates there is nearly always present, however, in addition to the soluble, the reverted form, which is probably quite as useful as the soluble form. The superphosphates made from boneblack and bone ash differ from the mineral superphosphates mainly in showing a higher content of "available" phosphoric acid, an average of 16 per cent, which is practically all soluble. Mineral superphosphates contain on the average 14 per cent of available, which may include from 1 to 3 per cent of reverted, besides more or less of the insoluble. Superphosphates made from animal bone differ from those made from the other materials mentioned in containing nitrogen in addition to phosphoric acid. They are, however, sometimes called "ammoniated superphosphates" or "dissolved ammoniated bone."

In the use of phosphoric acid, therefore, it must be remembered that the source has an important bearing in determining whether it is used as a phosphate or as a superphosphate. As regards the untreated phosphates, it must be remembered that those derived from organic substances, such as bone, are the more valuable because of their greater tendency to decay and greater ease of solution, and that this tendency to decay is promoted by such means as will increase the fineness of division. In the case of superphosphates, those which contain the greatest proportion of soluble phosphoric acid are relatively the most valuable, because the soluble phosphoric acid readily distributes itself in the soil and goes to the roots of plants, while the reverted remains where it is placed and the roots of the plants must come to it. In the next place, it should be remembered that phosphoric acid is not washed from the soil, though in a soluble form, since it is finally "fixed" by coming in contact with lime, iron, and other mineral substances usually present in good soils.

POTASH.

Potash may exist in a number of forms, though chiefly as chlorids, or muriates, in which case the potash is combined with chlorin; and as sulphates in which the potash is combined with sulphuric acid. With potash, however, the form does not exert so great an influence upon availability as is the case with nitrogen and phosphoric acid. All forms are freely soluble in water, and are believed to be nearly if not quite equally available as food. The form of the potash has, however, an important influence upon the quality of certain crops, due rather to the constituents with which the potash is associated than to the potash itself. For example, it has been demonstrated that the quality of tobacco, potatoes, and certain other crops is unfavorably influenced by the use

of muriate of potash, while the same crops show a superior quality if materials free from chlorids have been used as the source of potash applied.

The chief sources of potash salts at the present time are the Stassfurt mines of Germany, and the products of these mines, which are now readily obtainable in this country, are kainit, sylvinit, muriate of potash, high-grade sulphate of potash, and double sulphate of potash and magnesia, or double manure salts. The kainit and sylvinit are crude products of the mines, and contain, in addition to potash, a number of other salts, chiefly ordinary salt (sodium chlorid) and magnesium sulphate. The potash in kainit, though in the form of a sulphate, produces an effect quite similar to that derived from the use of muriate, because of the large quantities of chlorids mixed with it. It contains on the average about 12½ per cent of actual potash. Sylvinit differs from kainit in containing a slightly higher per cent of potash, which exists both in the form of a sulphate and of a chlorid, and a lower content of the magnesia and other salts. The other potash products mentioned are manufactured from the crude forms, and are much more concentrated. The muriate and sulphate contain on the average about 50 per cent of actual potash. The chief impurity in the case of the muriate is common salt. The double sulphate of potash and magnesia contains about 26 per cent of actual potash, though much lower grades of this material are found.

Materials that do not show a wide variation in composition, and in which the constituents are practically uniform in their action, may be regarded as standard in the sense that they can be depended upon to furnish practically the same amount and form of the constituents wherever secured. For example, a ton of nitrate of soda or boneblack superphosphate (dissolved boneblack) will on the average furnish 320 pounds of nitrogen or of phosphoric acid, the nitrogen all in the form of a nitrate and the phosphoric acid practically all soluble; whereas a ton of tankage, for instance, will vary widely both in the content and in the availability of its nitrogen and phosphoric acid, depending upon the method by which it has been derived. Hence, nitrate of soda, sulphate of ammonia, dried blood, and superphosphates and potash salts are standard products, because they can be depended upon both in respect to the content and form of their constituents.

AGRICULTURAL V. COMMERCIAL VALUE OF FERTILIZERS.

The agricultural value of any of the fertilizing constituents is measured by the value of the increase of the crop produced by its use, and is, of course, a variable factor, depending upon (1) the availability of the constituent, and (2) the value of the crop produced. For example, in the first case, the agricultural value of a pound of soluble phosphoric acid is likely to be greater than that of a pound of insoluble when applied under the same conditions as to soil and crop, because in the one case

the element is in its most available form, while in the other it is least available. In the second place, the soluble phosphoric acid may exert its full effect and cause a greatly increased yield on a certain crop, and still not cause an increase in value sufficient to pay the cost of the application, while for another crop the application may result in a very great increase in value. The character or form of the materials used must, therefore, be carefully considered in the use of manures. Slow-acting materials can not be expected to give profitable returns, particularly upon quick-growing crops, nor expensive materials such profitable returns when used for crops of relatively low value as for crops of relatively high value.

This agricultural value is, however, separate and distinct from what is termed "commercial value," or cost in market. This value is determined by market and trade conditions, as cost of production of the crude materials, methods of manipulation required, etc. Since there is no strict relation between agricultural and commercial or market value, it frequently happens that an element in its most available form, and under ordinary conditions of high agricultural value, costs less in market than the same element in less available forms and of a lower agricultural value. The cost of production in the one case is lower than in the other, though the returns in the field are far superior.

The commercial value has reference to the material as an article of commerce, hence commercial ratings of various fertilizers have reference to their relative cost and are used largely as a means by which the different materials may be compared.

VARIATIONS IN THE COMPOSITION OF MANUFACTURED FERTILIZERS.

All manufactured products or brands of fertilizers are made up of a mixture of the various kinds and forms of the fertilizing materials just described, and the differences that exist in the brands of different manufacturers are due both to differences in the character and to variations in the proportions of the materials used to form the different brands; that is, while all manufacturers must go to the sources of supply indicated, they may select either good or poor products and may vary the proportions of the different materials used.

The difference between a good brand of fertilizer and a poor one lies not so much in differences that may exist in the total amount of plant food contained in it as in the quality of the materials of which it is made. For instance, in one brand the nitrogen may have been derived entirely from insoluble organic materials and the phosphoric acid from untreated phosphates rather than superphosphates; while in another the nitrogen may have been derived from the three sources of nitrogen, viz, nitrates, ammonia salts, and organic matter, and the phosphoric acid entirely from superphosphates. In the first brand the total food contained may be quite as great as in the other, yet the immediate results obtained from its use would be less satisfactory than that

obtained from the one containing the more active forms of fertilizing constituents.

The differences that exist between good and poor fertilizers are quite clearly shown by the chemical analyses made by the various experiment stations, provided the analysis is carried far enough to show both the amount and form of the nitrogen, phosphoric acid, and potash. For instance, an analysis which shows that a considerable proportion of the nitrogen exists as nitrates or as ammonia is positive evidence that good nitrogenous materials have been used; if it shows that the phosphoric acid is largely in a soluble form, the consumer knows that superphosphates have been used. On the other hand, if all the nitrogen is shown to be in the form of organic matter, and that a large proportion of the phosphoric acid is insoluble, it is evident that materials containing less active forms of plant food have been used. In the next place, it is the quality and amount of plant food that is contained in a fertilizer which determines its value rather than the relative proportion of the various constituents, though under certain well-known conditions the latter is of very considerable importance. Special crop brands are particularly useful only when an abundance of all the plant-food constituents are present in the soil.

THE PURCHASE OF FERTILIZERS.

As a rule, farmers are inclined to purchase fertilizers on the ton basis, without sufficient regard to the content or form of the constituents contained in them. The direct value of a fertilizer is determined by the percentage of nitrogen, phosphoric acid, or potash which it contains. Hence, the buying of a fertilizer is virtually the buying of one or more of these constituents. The more concentrated the material or the richer it is in plant food the less will be the expense of handling the constituent desired.

The following are illustrations of the methods by which brands may be made up, the differences that may exist in the content of actual fertilizing constituents, and the causes of variation in ton prices:

Formula No. 1.

Nitrate of soda	500 lbs., furnishing nitrogen	80 lbs., or 4 p. ct.
Boneblack superphosphate	1,100 lbs., furnishing phosphoric acid	180 lbs., or 9 p. ct.
Muriate of potash	400 lbs., furnishing potash	200 lbs., or 10 p. ct.
Total	2,000 lbs., furnishing total plant food	460 lbs.

Formula No. 2.

Nitrate of soda	250 lbs., furnishing nitrogen	40 lbs., or 2 p. ct.
Boneblack superphosphate	1,000 lbs., furnishing phosphoric acid	160 lbs., or 8 p. ct.
Muriate of potash	80 lbs., furnishing potash	40 lbs., or 2 p. ct.
Make-weight	670 lbs.	
Total	2,000 lbs., furnishing total plant food.	240 lbs.

Formula No. 1 shows a high-grade product, both in respect to quality of plant food and concentration, while No. 2 is high-grade only in respect to quality. In order that the plant food may be contained in 1 ton it is necessary to add what is called "make-weight," or a diluent, usually consisting of substances that contain no direct fertilizing value.

"High-grade mixtures can not be made from low-grade materials. Low-grade mixtures can not be made from high-grade materials without adding 'make-weight.' The advantages of high-grade products are concentration and high quality of plant food."[1]

It will be observed that formula No. 1 contains nearly twice as much plant food as No. 2; or, in other words, it will require about 2 tons of a fertilizer made according to formula No. 2 to secure the same total amount of plant food as is contained in 1 ton of No. 1. Now, the material in No. 2 other than the actual plant food is of no direct fertilizing value, but the actual cost of the constituents is considerably increased, because the expenses of handling, bagging, shipping, and selling are just double what they would be for No. 1.

It has been shown by continued studies at the New Jersey Experiment Station that the charges of the manufacturers and dealers for mixing, bagging, shipping, and other expenses are, on the average, $8.50 per ton; and also that the average manufactured fertilizer contains about 300 pounds of actual fertilizing constituents per ton. A careful study of the fertilizer trade indicates that these conditions are also practically true for other States in which large quantities of commercial fertilizers are used.

Formula No. 1 would contain 460 pounds of actual available fertilizing constituents per ton—160 pounds, or over 50 per cent, more than is contained in the average manufactured brand. That is, a farmer purchasing a brand similar to formula No. 1 would secure in 2 tons as much plant food as would be contained in 3 tons of the average manufactured brand. Assuming that the charges per pound of plant food at the factory, and that the expense charges are the same in each case, and also that the quality of plant food in the one is as good as in the other, the consumer would save $8.50 by purchasing 2 tons of the former instead of 3 tons of the latter. In a few States the consumption of **fertilizers ranges from 150,000 to over 300,000 tons annually, while in many it is from 25,000 to 50,000 tons.**

Thus is shown the very great saving that may be effected in the matter of the purchase of fertilizers from the standpoint of concentration alone, or, in other words, the importance of a definite knowledge of what constitutes value in a fertilizer. This saving may be accomplished, too, without any detriment to the manufacturer, since the difference to him between making high-grade or low-grade goods, in reference to concentration, is largely a matter of unskilled labor. The manufacturers are in the business to cater to the demands of the trade;

[1] First Principles of Agriculture, E. B. Voorhees, p. 109.

if consumers are intelligent, high-grade rather than low-grade goods will be provided by the manufacturers. Furthermore, as already indicated, high-grade in the matter of concentration means high-grade in quality, for high-grade mixtures can not be made from low-grade products.

In many cases, too, it is desirable to purchase the unmixed fertilizing materials, either for use singly or to be mixed at home. Here, too, a great saving may be effected—(1) in the cost per pound of the constituents; (2) in freight rates, and (3) in having the mixing performed by the ordinary labor of the farm, at times when it does not interfere with regular outdoor work. The advantages to be derived from this method are, however, fully realized only when it is possible to purchase in large quantities for cash.

As an illustration of the saving that may be effected, it is but necessary to cite the experience of a farmers' organization in New Jersey, which now purchases annually some 500 or 600 tons of unmixed goods. The cost per pound of the ingredients is to them over 40 per cent less than the average cost to those who buy the average mixture in small quantities "on time" from their local dealers.

It has been shown, too, by the studies of many of the experiment stations of both the East and South that the materials can be evenly mixed on the farm; besides, samples carefully taken show as good a mechanical condition as those made by the leading manufacturers.

This method of purchasing also possesses the further advantage of enabling the farmer to apply just the kind and form of ingredient that he has found by experience or experiment to be best adapted to his soil and crop. Besides, he knows positively, particularly in case of the element nitrogen, whether it is in the form of nitrate, ammonia, or organic matter, and whether the organic nitrogen is contained in substances that are likely to decay quickly, as blood, cotton-seed meal, etc., or in such insoluble and slow-acting substances as ground leather, horn, etc. In mixtures the kind of organic nitrogenous substances used can not be definitely shown by a chemical analysis.

CONDITIONS UNDER WHICH FERTILIZERS MAY BE PROFITABLY USED.

With a more or less complete knowledge of the need of artificial supplies of fertilizer, the character, composition, and usefulness of the various materials, and the best method of purchase, the practical question arises, Will it pay to use them? Many of our most successful farmers are by their practice answering this question in the affirmative. It is, however, not entirely a question of plant food with them, and one phase of it may be illustrated by the following typical case: Mr. A applies fertilizer, his crop is doubled or tripled, and a reasonable profit is secured. Mr. B applies the same amount and kind under similar natural conditions of soil and receives no benefit. The difference in results is due not to the fertilizer, but to the farmer himself. In

one case the natural agencies—sun, air, and water—were assisted and enabled to do their maximum work, because care was taken to make the conditions other than the supply of plant food as perfect as possible, while in the other they were prevented from exercising their full influence because physical conditions of soil were imperfect, due to careless plowing, seeding, cultivation, and cropping.

In other words, the profit from the use of fertilizers is measured to a large degree by the perfection of soil conditions which are entirely within the power of the farmer to control. The production possible from a definite amount of plant food can be secured only when the conditions are such as to permit its proper solution, distribution, and retention by the soil.

The fact that fertilizers may now be easily secured and are easily applied has encouraged careless use rather than a thoughtful expenditure of perhaps an equivalent amount of money or energy in the proper preparation of the soil for them. Of course it does not follow that no returns are secured from plant food applied under unfavorable conditions, but it needs to be emphasized that full returns can not be obtained under such circumstances either with or without fertilizers. Good plant food is wasted and the profit possible to be derived is largely reduced. Moreover, farming in its strict sense is the conversion of three essential elements into salable products, and therefore the use of plant food must be governed largely by its cost, and the kind of crop upon which it is applied.

The very high prices paid by many for fertilizers—though admittedly due to their lack of knowledge concerning what constitutes value in a fertilizer and to irrational methods of buying—renders it impossible to secure a reasonable profit by their unsystematic use upon such staple products as wheat, corn, oats, cotton, and tobacco, because these crops absorb relatively large amounts of the manurial constituents, and are at the present time products of relatively low value.

The bushel or pound of crop contains a high content relatively of the fertilizing constituents while the selling price is low, thus leaving but a narrow margin between the cost of the constituent and the price received for it in the product.

The growth of such crops as potatoes, tomatoes, sweet potatoes, forage crops for the dairy, and vegetable crops for the market or cannery by the use of high-priced plant food is more often attended with profit, because they are usually crops of high market value and are proportionately less exhaustive. This does not mean that the former crops shall be abandoned, but rather that our systems of practice shall be changed so as to include in the rotation some high-priced crop to which shall be applied such an abundance of plant food as to insure a yield, limited only by the season and climate, which will, under average conditions of soil and season, yield a profit, besides leaving a residue of plant food for the cereals, grasses, or catch crops that follow. These

being capable of extracting their mineral food from relatively insoluble sources will yield a large increase of crop without a direct outlay for fertilizers. Farming will thus be more successful, because profitable crops are secured, while at the same time fertility is increased.

THE KIND OF FERTILIZER TO USE.

The kind of fertilizer to use should be considered (1) in reference to whether it shall be nitrogenous, phosphatic, or potassic in its character, and not to whose brand shall be used; and (2) as to the form in which the fertilizing constituents exist, whether quickly or slowly available. A proper understanding of these points requires that we shall consider briefly the various classes of farm crops and their power of acquiring food.

The cereals, Indian corn excepted (see p. 23), and grasses are quite similar in their habits of growth, and may be regarded as a class distinguished by extensive root systems and long periods of growth, which enable them to extract the mineral food necessary from relatively insoluble sources, and because of their very rapid development of leaf and stem during a short season just before maturity are unable to make normal growth during this period without an abundance of nitrogen in immediately available forms. This period usually precedes the time of rapid nitrification; hence on soils of good natural fertility the application of nitrogen at the right time and in the form of a nitrate results in a largely increased crop. The fact here stated has led certain eminent scientists to regard nitrogen as a dominant or ruling element for this class of plants, and it is true if the limitations are properly understood.

The leguminous crops—clover, peas, beans, vetches, etc.—should also be regarded as a distinct class. They possess powers of acquiring food which, as far as we know now, are not common to any other class of plants. They do not depend altogether upon soil sources for their nitrogen, but draw this element partly from the air, and they make almost ravenous use of the mineral constituents, particularly potash and lime. A knowledge of these facts is not only useful in indicating what kind of manures to use, viz, an abundance of the mineral constituents only, but suggests that the growth of these crops must result in the enrichment of soils in the expensive element, nitrogen, so essential for crops whose exclusive source of supply is the soil.[1]

Root and tuber crops may also be regarded as a class which, because of their habits of growth, are unable to make ready use of the insoluble mineral constituents of the soil, and hence for full development require an abundance of all the fertilizing constituents in readily available forms. Of the three classes of fertilizing constituents, the nitrogen is especially useful for the slow-growing beets and mangels; soluble phosphates are required in abundance for the turnip; and potatoes,

[1] Farmers' Bul. 16 of this Department.

white and sweet, respond favorably to liberal dressings of potash. That is, while the fertilizers should contain all three elements, certain of the crops, because of their peculiarities of growth, require certain of them in greater relative amounts and in immediately available forms.

The object of the growth, too, whether for the immature produce or for the fully developed plant, is a matter worthy of careful consideration. In other words, Shall the fertilizing be of such a character as to stimulate and force an unnatural and artificial growth, or such as assists in the natural development of the plant? That the specific function of nitrogenous manures is to encourage and even force leaf development is a fact not disputed by the highest authority; hence their use in stimulating unusual growth is of the greatest importance in growing market-garden crops, in order that the tenderness and succulence, which is the measure of quality in most of those products, may be secured.

Fruit trees are slow-growing plants and therefore do not need quick-acting fertilizers as a rule. They appropriate plant food very slowly, and highly soluble manures, such as nitrate of soda, are liable to be washed out of the soil without being utilized. For this reason the use of nitrate of soda is not advised except where the growth of nursery stock is to be forced or where bearing trees exhibit a lack of luxuriance in foliage. The old and still common practice of fertilizing fruit trees every few years with slowly decomposing manures, such as barnyard manure, leather waste, horn refuse, wool waste, leaf mold, tobacco stems, etc., is thus seen to have more or less of a scientific basis. Frequently, however, it is desirable to stimulate the growth and fruitfulness of the trees, and for this purpose more active fertilizing materials than the above are needed. In selecting and mixing the latter the fact that fruits are "potash feeders" should be taken into consideration.

Probably there is no better fertilizer for fruit trees than a mixture of muriate of potash and ground bone (1 part of the former to 1½ parts of the latter). A good practice is to apply this mixture to clover or some other leguminous crop which is turned under as a green manure, and in addition, where tobacco stems can be obtained cheaply, to apply these about the trees. Wood ashes or cotton-hull ashes may be substituted for muriate of potash if these products can be obtained at reasonable prices.

The fertilizer requirements of small fruits are similar to those of orchard fruits, but being as a rule more rapid growers they can utilize to advantage heavier applications of soluble fertilizing materials and do not derive the same benefit as orchard fruits from slowly decomposing manures.

In deciding upon the kind of manure to use the character of the soil must, of course, be taken into account. Crops grown on soils poor in decaying vegetable matter (humus) are as a rule benefited by applications of nitrogenous manures, while those grown upon soils well

supplied with this substance are more benefited by phosphates and potash. Upon heavy soils phosphates are likely to be more beneficial than nitrogen, while the reverse is the case on light dry soil. All sandy soils are as a rule deficient in potash, while clayey soils contain this element in larger quantities (see p. 7).

In this discussion the barest outlines have been drawn. There are many exceptions to the general rules. The farmer, with the general principles well in mind, must use his intelligence in applying them to his conditions.

FERTILIZERS SHOULD BE APPLIED SYSTEMATICALLY.

The suggestions already given lead to another of great importance, viz, that the use of fertilizers should be systematic. In order that this may be accomplished, a definite system of cropping should be adopted and a definite scheme of manuring worked out that shall meet the conditions of crop, season, and climate, and enable the farmer to utilize to the best advantage home and local supplies of manure. While it is impossible to give more than the merest outline of such methods, the following suggestions are offered:

In the first place, in nearly every State or even locality some one system of cropping is better adapted to the conditions than another. It may be the extensive system, which includes large areas, and the crops, grain, cotton, tobacco, or sugar cane; or the "intensive system," with smaller areas and crops of quicker growth and higher value. For the former a method of manuring should be adopted which is not too expensive, but which provides for increased crops and gradual gain in fertility. It would be impracticable in extensive farming, for example, to attempt to increase the yield of a wheat crop from 12 to 30 bushels per acre by the addition of fertilizers only, for, as already pointed out, plant food is but one of the conditions of fertility, and if it were practicable from the standpoint of yield, it would be folly from the standpoint of profit.

A study of the following common four-year rotations—Indian corn, potatoes, wheat, and hay—will illustrate what is meant by rational and systematic methods of manuring. On soils of medium fertility spread the farm manure during the fall and winter, and after the land is plowed apply broadcast and harrow in, or harrow first and then drill in, 400 pounds per acre of a mixture made of 100 pounds each of cotton-seed meal, ground bone, acid phosphate, and muriate of potash, or their equivalent in kind and form of other fertilizing constituents.

This mixture would have approximately the following composition: Nitrogen 2.5 per cent, phosphoric acid 10 per cent, and potash 12.5 per cent. If the land has not been previously manured, or if it is of a light sandy character, the proportion of nitrogenous matter should be increased and the application be heavier, say, from 600 to 800 pounds.

Corn makes its most rapid growth and development during the hot season, which is very favorable for rapid decay and consequent nitrification of organic substances in the soil. The nitrogenous manures, therefore, may be less in amount than for crops which develop rapidly earlier in the season, and for the same reason may consist of organic forms. The mineral constituents, particularly the phosphates, which the crop acquires less readily, because of its comparatively short season of growth, are applied in such forms and in such amounts as to provide for a largely increased crop, even though the seasonal conditions are not perfect.

For the potatoes, as a minimum application 650 pounds per acre of the following mixture may be used:

Fertilizer for potatoes.

	Pounds.
Nitrate of soda	50
Cotton-seed meal	150
Ground bone	100
Acid phosphate	200
Muriate or sulphate of potash	150

This mixture contains—nitrogen 3 per cent, phosphoric acid 8 per cent, and potash 12 per cent. In this application we are guided by certain other well-defined principles, chief of which are: This is usually the money crop of the rotation; we can therefore afford a more expensive manuring. Since it grows and matures in a comparatively short time, we need to furnish a reasonable excess of plant food in order that the crop may be abundantly supplied even though unfavorable conditions occur. It is a crop which is particularly benefited by potash, and we must therefore provide that element in largest proportion; and as it is not an exhaustive crop, we may expect considerable increase in soil fertility due to the unused residue.

After the potatoes are removed the land, on account of the frequent cultivation of the potato crop, is in fine mechanical condition essential for the rapid germination and early growth of wheat. It is also well supplied with plant food because of the manure applied to the previous crops in excess of their needs.

For the wheat, therefore, such home supplies of manure as are available may be applied after plowing and well worked into the surface soil with the addition at time of seeding of 200 pounds per acre of dissolved bone, or a mixture of 100 pounds each of ground bone and acid phosphate. In spring, if the crop does not show a vigorous condition, sow broadcast 100 pounds per acre of nitrate of soda.

By this method the manuring is accomplished at a minimum expense, and the phosphates which are so essential for the proper development of the grain are provided, partly in an immediately available form, partly in a form that will gradually decay and feed the crop at later stages of growth. The nitrogen is applied when the plant has greatest

need for it and in a form immediately available, while for potash the plant depends entirely upon the accumulated soil supplies. The hay crop which follows, if it consists of clover, will be able to make normal growth with added supplies of phosphoric acid and potash only, which may consist of a mixture of equal parts of acid phosphate and muriate of potash at the minimum rate of 200 pounds per acre.

This method of fertilizing should not be changed from year to year, but followed in the succeeding rotation courses, and it will enable the farmer to secure an increased yield and improvement in soil at a minimum expense.

The principles involved may also be applied in other lines of farming, modified by character of soil, climate, and kind of crop. In market gardening the amounts applied should be proportionately increased, and a larger proportion of the more active forms used, because in this case quick-growing crops which belong to the high-value class are produced. For fruit trees, which feed slowly and continuously, the mineral elements, as already explained, should be applied in greater amounts, and may be derived from the cheaper and more slowly available forms.

SUMMARY.

(1) Commercial fertilizers are mainly valuable because they furnish the elements—nitrogen, phosphoric acid, and potash—which serve as food, not as stimulants.

(2) The kind of farming in the past and the demands for special products in the present make their use necessary in profitable farming.

(3) In order to use them profitably the farmer should know—

(*a*) That nitrogen, phosphoric acid, and potash are the essential manurial constituents;

(*b*) That the agricultural value of these constituents depends largely upon their chemical form;

(*c*) That these forms are contained in specific products of a well-defined character and composition, and may be purchased as such from dealers and manufacturers and may be mixed successfully on the farm.

(4) The agricultural value of a fertilizer bears no strict relation to the commercial value; the one is determined by soil, crop, and climatic conditions, the other by market conditions.

(5) The variations in the composition and value of manufactured fertilizers which contain the three essential constituents are due to variations in the character and in the proportion of the materials used.

(6) The ton basis alone is not a safe guide in the purchase of these commercial fertilizers. Low ton prices mean either low content of good forms of plant food or the use of poorer forms. Fertilizers, high-grade both in quality and quantity of plant food, can not be purchased at a low price per ton.

(7) The best fertilizers can not exert their full effect on soils that are too dry or too wet, too compact or too porous. They can furnish but one of the conditions of fertility.

(8) The kind and amount to use should be determined by the value of the crop grown and its power of acquiring food.

(9) A definite system or plan should be adopted in their use; "hit or miss" methods are seldom satisfactory, and frequently very expensive.

Composition of the principal commercial fertilizing materials.

	Nitrogen.	Available phosphoric acid.	Insoluble phosphoric acid.	Total phosphoric acid.	Potash.	Chlorin.
1. Supplying nitrogen:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Nitrate of soda	15.5 to 16					
Sulphate of ammonia	19 to 20.5					
Dried blood (high grade)	12 to 14					
Dried blood (low grade)	10 to 11			3 to 5		
Concentrated tankage	11 to 12.5			1 to 2		
Tankage (bone)	5 to 6			11 to 14		
Dried fish scrap	7 to 9			6 to 8		
Cotton-seed meal	6.5 to 7.5			1.5 to 2	2 to 3	
Castor pomace	5 to 6			1 to 1.5	1 to 1.5	
2. Supplying phosphoric acid:						
South Carolina rock phosphate			26 to 28	26 to 28		
South Carolina rock superphosphate (dissolved South Carolina rock phosphate)		12 to 15	1 to 3	13 to 16		
Florida land rock phosphate			33 to 35	33 to 35		
Florida pebble phosphate			26 to 32	26 to 32		
Florida superphosphate (dissolved Florida phosphate)		14 to 16	1 to 4	16 to 20		
Boneblack			32 to 36	32 to 36		
Boneblack superphosphate (dissolved boneblack)		15 to 17	1 to 2	17 to 18		
Ground bone	2.5 to 4.5	5 to 8	15 to 17	20 to 25		
Steamed bone	1.5 to 2.5	6 to 9	16 to 20	22 to 29		
Dissolved bone	2 to 3	13 to 15	2 to 3	15 to 17		
Thomas slag				[1]11.4 to 23		
3. Supplying potash:						
Muriate of potash					50	45 to 48
Sulphate of potash (high grade)					48 to 52	.5 to 1.5
Sulphate of potash and magnesia					26 to 30	1.5 to 2.5
Kainit					12 to 12.5	30 to 32
Sylvinit					16 to 20	42 to 46
Cotton-hull ashes [2]				7 to 9	20 to 30	
Wood ashes (unleached) [2]				1 to 2	2 to 8	
Wood ashes (leached) [2]				1 to 1.5	1 to 2	
Tobacco stems	2 to 3			3 to 5	5 to 8	

[1] In good Thomas slag at least 80 per cent of the phosphoric acid should be soluble in ammonium citrate, i. e., available.

[2] Cotton-hull ashes contains about 10 per cent of lime, unleached wood ashes 30 to 35 per cent, and leached wood ashes 35 to 40 per cent.

FARMERS' BULLETINS.

These bulletins are sent free of charge to any address upon application to the Secretary of Agriculture, Washington, D. C. Only the following are available for distribution:

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No. 16. Leguminous Plants for Green Manuring and for Feeding. Pp. 24.
No. 18. Forage Plants for the South. Pp. 30.
No. 19. Important Insecticides: Directions for Their Preparation and Use. Pp. 20.
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FARMERS' BULLETIN No. 44.

COMMERCIAL FERTILIZERS:

COMPOSITION AND USE.

BY

EDWARD B. VOORHEES, M. A., D. Sc.,

Director of the New Jersey Agricultural Experiment Stations and Professor of Agriculture in Rutgers College.

UNDER THE SUPERVISION OF THE OFFICE OF EXPERIMENT STATIONS.

[Revised March, 1906.]

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1906.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., March 8, 1906.

SIR: I have the honor to transmit herewith and to recommend for publication a revision of Farmers' Bulletin 44 on Commercial Fertilizers, prepared by E. B. Voorhees, director of the New Jersey Agricultural Experiment Stations. In this revision the original bulletin has been practically rewritten and the information brought up to date.

Respectfully,

A. C. TRUE, *Director.*

Hon. JAMES WILSON,
Secretary of Agriculture.

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COMMERCIAL FERTILIZERS.

There is, perhaps, no question of greater importance to the practical farmer than that of soil fertility. To produce profitable crops and at the same time to maintain and even to increase the productive capacity of the soil may rightly be termed "good farming." Many farmers are able to do this, and the knowledge of how to do it has been largely acquired through years of experience, during which the character of the soil, its adaptability for crops, and the methods of its management and manuring have been made the subjects of careful study, without, however, any definite and accurate knowledge concerning manures and their functions in relation to soils and crops. Experience is an excellent teacher, still a definite knowledge of the fundamental principles may be substituted for years of experience in the successful use of manures.

MANURIAL CONSTITUENTS OF FARM PRODUCTS.

The fertility of the soil would remain practically unchanged if all the ingredients removed in the various farm products were restored to the land. This is to a large extent accomplished by feeding the crops grown on the farm to animals, carefully saving the manure and returning it to the soil, and where it is practicable to pursue a system of stock feeding in which those products of the farm which are comparatively poor in fertilizing constituents are exchanged in the market for feeding stuffs of high fertilizing value, the loss of soil fertility may be reduced to a minimum, or there may be an actual gain in fertility.

The following table, showing the amounts of fertilizing constituents in 1 ton of different agricultural products, indicates directions in which such an exchange may be effected with advantage:

Manurial constituents contained in 1 ton of various farm products.

Farm product.	Manurial constituents.		
	Nitrogen.	Phosphoric acid.	Potash.
	Pounds.	*Pounds.*	*Pounds.*
Timothy hay	19.2	7.2	25.2
Clover hay	39.4	8.0	35.0
Alfalfa hay	53.2	10.8	49.2
Cowpea hay	49.6	13.2	47.2
Corn fodder, field cured	17.2	7.2	21.4
Corn silage	8.4	2.4	6.6
Wheat straw	8.6	2.6	14.8
Rye straw	10.0	5.8	15.8
Oat straw	13.0	4.4	24.4
Wheat	34.6	19.2	7.0
Rye	32.4	16.2	10.4
Oats	36.2	15.4	11.4
Corn	29.6	12.2	7.2
Barley	39.6	15.4	9.0
Wheat bran	51.2	58.4	31.4
Linseed meal	108.6	37.6	26.2
Cotton-seed meal	142.8	61.8	36.4
Potatoes	7.0	3.2	11.4
Milk	10.2	3.4	3.0
Cheese	90.6	23.0	5.0
Live cattle	53.2	37.2	3.4

The exchange of 1 ton of corn for 1 ton of wheat bran, for instance, will result in a gain of 21 pounds of nitrogen, 46 of phosphoric acid, and 24 of potash. With an exchange of milk or potatoes for the concentrated feeding stuffs the gain is still more striking.

NEED OF COMMERCIAL FERTILIZERS.

A careful study of the present condition of farming in the United States indicates, however, that as a rule the manure produced on the farm is not sufficient to maintain its fertility, and that the need for artificial supplies is real, though the amount required may be considerably reduced by careful management.

Effects of grain farming.—In the system of so-called "grain farming," which has obtained over large areas of this country for a long time, and is still practiced, the live stock is often limited to a number sufficient only to the needs of the farm for labor and food; the grain is sold, and the manure is made up chiefly of the natural wastes or unsalable material, such as straw, stalks, etc. The grain contains proportionately greater amounts of nitrogen and mineral constituents than these wastes; hence the practice continued for a long time results not only in a deficiency in the soil of organic substances containing nitrogen, but also in an exhaustion of the mineral substances. The original character of the soil and its treatment measure the rate of exhaustion. The less fertile soils of the East and South are rapidly depleted, while the rich prairies and river bottoms maintain their fertility for a longer period.

Effects of one-crop farming.—The continuous cotton and tobacco growing of the South and the wheat growing of the West are even

more exhaustive, since here the demands upon the soil are not changed—year after year the same crop is grown and the same kind and proportion of constituents are required, while even slighter returns are made in the way of manure than in the system of farming just described. Under such conditions the decomposition of the organic matter in the soil is accompanied by proportionately greater losses of nitrogen. Moreover, the land is left bare for a large part of the year, and its fertility is thereby still further decreased. The crops become less abundant each year, not because the soil is entirely exhausted, but because it is so far exhausted of those constituents essential to the special crop grown that its production is no longer profitable.

Changed conditions of farming, which have an important bearing on this point, are: (1) Increased cost of labor and lower prices of many of the products of one-crop farming, and (2) an increasing demand for market-garden products and fruit. For example, in growing wheat, the labor of preparing the soil, of sowing, and of harvesting is practically the same whether the yield is 10 bushels per acre or 30 bushels, and the same is true of a number of other crops; hence in case of the larger yield the cost of labor per bushel is materially reduced. Meager crops of a relatively low value can not be produced profitably with high-priced labor. Soils of a high degree of fertility are required in order to produce large yields of these crops. The return to the soil of only the wastes of the farm leads sooner or later to a decreased fertility, however good the management may be; hence the need of supplies of plant food from sources outside the farm in order that maximum crops may be produced.

Market gardening and fruit growing.—It has been demonstrated, in the case of market-garden crops, that even very fertile soils contain too little available food to insure a maximum production. This is especially true where rapidity of growth, earliness, and high quality of produce are important factors. The areas now necessarily devoted to these crops are so great that the amount of farm manures available is much too small; besides, the constituents contained in such manures, being in part but slowly available, are less useful than the more active forms contained in commercial fertilizing materials. Market-garden crops are in a sense artificial crops, and, as a rule, need artificial supplies of plant food.

Fruit culture, an industry of growing importance, is profitable, particularly on the poorer soils near the eastern markets, largely in proportion of the amounts of the mineral elements applied in excess of those contained in soils otherwise well adapted to the crops. A proper supply of food not only enables the trees to resist unfavorable

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conditions, but improves the quality of the fruit and prolongs the bearing period of the orchards and vineyards.

It will be thus seen that commercial fertilizers can be used most advantageously either in reenforcing farm manures in general, or in providing a generous supply of quickly available plant food in specialized, intensive farming. It should be the aim in applying such fertilizers to supplement rather than to replace entirely the manurial resources of the farm, for the best results from their application may be secured only on soils well stocked with organic matter (humus), a material that can be maintained in the soil only by the systematic application of the bulky barnyard or green manures.[a]

FERTILIZER REQUIREMENTS OF DIFFERENT SOILS AND CROPS.

Essential fertilizing constituents.—Nitrogen, phosphoric acid, and potash are the constituents most likely to be deficient in soils or most quickly exhausted by the production and removal of crops. They are known as "essential" fertilizing constituents, and the value of a commercial fertilizer is determined almost exclusively by the amount and form of the nitrogen, phosphoric acid, and potash which it contains. It does not follow, however, that all soils or crops will respond equally to applications of materials containing these elements, for the needs of soils and the requirements of crops vary.

Differences in soils.—Soils differ as to their needs for specific fertility elements, owing either to their method of formation or to their management and cropping. A sandy soil is usually deficient in all the essential plant-food constituents—nitrogen, phosphoric acid, and potash—while a clayey soil usually contains the mineral elements in abundance, particularly potash. On the other hand, a soil very rich in vegetable matter is frequently deficient in mineral matter, while a limestone soil is likely to contain considerable proportions of phosphoric acid. These are the indications in a general way, and they explain why it is that different kinds of soil that have not been cropped differ as to their need of the different fertilizing constituents.

Differences in farm management.—Methods of management and cropping also exert an influence; for example, soils of equal natural fertility may not respond equally to uniform methods of fertilization, because in the one case a single crop, requiring for its growth proportionately more of one of the essential elements than of another, is grown year after year, and it may be that the element required is the one that exists in the soil in least quantity. On the other hand, crops may be grown that demand but minimum amounts of the element in question; hence its application to the soil for the one

[a] See U. S. Dept. Agr., Farmers' Buls. 192 and 245.

crop may be followed by largely increased returns, while for the other but little if any increase in crop is apparent.

In the matter of management, too, a considerable variation may be observed. One soil may lose a large portion of its essential constituents, because no pains are taken to retain for the use of the crop the plant food annually rendered available through the natural agencies of sun, air, and water; while in another, by means of careful cultivation and the use of absorbents and catch crops, the constituents made available are largely retained.

Differences in power of crops to acquire food.—The legumes—a class of plants which includes the various clovers, peas, beans, vetches, etc.—differ from other plants in being able, under proper conditions, to acquire their nitrogen from the air through the aid of organisms working in their root tubercles,[a] and can, therefore, make perfect growth without depending upon soil nitrogen. On the other hand, the various grasses and grains are not only dependent upon soil nitrogen, but they must have an abundance during their period of most rapid growth in order to attain their maximum development. For the latter class of plants favorable results are secured from the proper use of nitrogenous manures, while for the former class the application of nitrogenous manures simply results in supplying an element which could have been secured quite as well by the plant itself without expense. Illustrations could be multiplied, though they be less striking than this, showing that the variations in crops in respect to their power of acquiring food are really very great, and a right knowledge of this fact has a most important bearing upon the economical use of commercial manures.

Importance of knowing needs of soils and crops.—The variations in the needs of soils and crops make it desirable that every farmer should know his own particular requirements. Such information may be secured more easily than is commonly supposed by growing the same crop and under the same conditions with different fertilizers. The knowledge thus obtained could be made quite valuable for any given locality, and may serve an important purpose in indicating the most economical use of fertilizer materials. While such tests are not so difficult or expensive as is often supposed, it is recommended that before the farmer undertakes them for the first time he seek the advice of some one familiar with the details of such work, or, better still, apply to the experiment station of his State.

FERTILIZING MATERIALS.

Form of fertilizing constituents.—The term "form," as applied to a fertilizing constituent, has reference to its combination or associa-

[a] See U. S. Dept. Agr., Farmers' Bul. 240.

tion with other constituents, which may be useful, though not necessarily so. The form of the constituent, too, has an important bearing upon its availability, and hence upon its usefulness as plant food. Many materials containing the essential elements are practically worthless as sources of plant food, because the form is not right; the plants are unable to make use of them—they are "unavailable." In many cases the form of these materials is changed by proper treatment and they become valuable, not because the element itself is changed, but because it then exists in such form as readily to feed the plant.

NITROGEN.

Nitrogen is the most expensive of the three essential fertilizer elements. It exists in fertilizers in three distinct forms, viz, as organic matter, as ammonia, and as nitrate.

Organic Nitrogen.

Organic nitrogen exists in combination with other elements, either as vegetable or animal matter. In fact, all plants and animals contain nitrogen in this form, and the relative value of the various substances as sources of nitrogen depends upon their content of it and upon the character of the substances and their treatment. All materials containing organic nitrogen are valuable in proportion to their rapidity of decay or change, because decay and change of form must take place before the nitrogen can serve as food. In some cases the decay is longer delayed than in others. The material may be hard and dense, or it may have been treated for the express purpose of preventing decay, or it may be associated with other substances that resist the agents which effect decay. Thus organic nitrogen differs in availability not only according to the kind of material which supplies it, but according to the treatment it receives.

The most abundant supplies of nitrogen occur in organic forms. The most valuable sources of organic nitrogen, from the standpoints of uniformity in composition, richness in the constituent, and availability, are dried blood, dried meat (or azotine), and concentrated tankage, which are produced in large quantities in slaughterhouses and rendering establishments; dried fish, refuse from fish-oil and fish-canning establishments, and cotton-seed meal, the residue of the cotton seed after the oil has been extracted. These vary somewhat in composition, but within comparatively narrow limits. (See table, p. 37.) They are all rich in nitrogen, and they decay rapidly when the conditions are favorable; and they are, therefore, very useful in cases where rapid and continuous feeding of the plant with nitrogen is desirable. Their gradual change makes them particularly valuable in light, open soils, from which the nitrate or ammonia nitrogen

tends to disappear too quickly. Moreover, the chemical substances produced in the decay of the nitrogenous organic matter help to dissolve some of the mineral ingredients of the soil and increase thereby the amount of available phosphoric acid, potash, and lime.

These products, while valued principally as sources of nitrogen, also furnish more or less phosphoric acid, the dried blood and meat showing the least and the fish the greatest amount. Other nitrogenous materials which are less desirable are leather meal, wool waste, felt waste, and similar products. These contain, as a rule, a high proportion of nitrogen, but they are so very slow to decay that it is doubtful whether their use in their original form is advisable when forms of known value are available at reasonable prices. Where the object is gradually to increase the fertility of the soil rather than to secure immediate returns, they may become useful. Farmers frequently have access to local supplies at a slight cost, the chief expense being the labor of carting and distributing, in which case they are worth considering.

Nitrogen as Ammonia.

Nitrogen as ammonia exists in commercial manure products in the form of sulphate of ammonia, chlorid of ammonia, etc., and is more readily available than the nitrogen in organic forms. It is one of the first products that result from the decay of organic substances.

Ammonia nitrogen is derived, almost exclusively, from sulphate of ammonia, one of the most concentrated materials which furnish nitrogen for fertilizer purposes, the commercial products containing, on the average, 20 per cent of nitrogen. This form of nitrogen is readily converted in the soil into nitrate, and is therefore a valuable source of highly available nitrogen. Until it is changed into nitrate, the ammonia nitrogen has the power of combining with certain organic and mineral substances in the soil, and in this condition can resist the leaching action of rain. For this reason it serves as a more economical source of nitrogen in periods of excessive rainfall, and particularly in open soils, than does nitrate, which may be quite easily washed out from the soil. The use of large quantities of sulphate of ammonia leads in time to a very marked increase of soil acidity, for the ammonia is taken up by the crops in larger proportion than is the sulphuric acid with which it is combined. The latter accumulates in the soil and may seriously diminish the yields unless care is taken to neutralize the acid by generous applications of lime.

Nitrogen as Nitrate.

Nitrogen as nitrate exists in commercial products as nitrate of soda, nitrate of potash, etc. These, like the ammonia compounds, are

extremely soluble, and the nitrogen contained in them is readily available as food for plants. The nitrogen in this form is directly and immediately available, no further changes being necessary.

Chief source.—The chief source of nitrate nitrogen is nitrate of soda. This salt is rich in nitrogen, containing on the average 15.5 per cent of it, and is quite uniform in composition. It is completely soluble in water, diffuses readily throughout the soil, and differs from the ammonia compounds in forming no insoluble compounds with soil constituents. It is, therefore, liable to be partly washed out of the soil if applied in too large quantities or when there is an absence of vegetation. Plants that derive their nitrogen from the soil secure it chiefly in the form of a nitrate; hence nitrate of soda is one of the most directly useful of the nitrogenous materials.

As already explained, nitrogen in organic forms is changed into ammonia by the decay or rotting of the substance. Ammonia, while it may nourish plants directly, is usually changed into a nitrate, in which form it is taken up by the plant. An application of nitrogen as nitrates may be completely used up by the plant in a very short time; as ammonia or organic matter it may be partially or wholly used in the course of a season, according as the conditions are favorable or unfavorable for the changes which they must undergo.

Comparisons of Organic, Ammonia, and Nitrate Nitrogen.

Losses of nitrogen.—It is clear, in view of the foregoing, that organic, ammonia, and nitrate nitrogen have a very unequal value as sources of nitrogen to plants. Even the nitrate nitrogen, the most valuable of the three, is not wholly utilized by the crop. The conditions are seldom, if ever, realized when 100 per cent of the nitrate nitrogen applied reappear in the harvest, for a smaller or larger proportion of it escapes beyond the reach of the plant roots. In seasons of excessive rainfall, the proportion of nitrate nitrogen that thus escapes into the subsoil may be very large—50 per cent or more of the total quantity applied. Still another source of loss to which the nitrate nitrogen is exposed is known as *denitrification;* that is, the destruction of the nitrate by certain bacteria, with the setting free of the nitrogen as a gas which escapes into the atmosphere, and is, therefore, lost to the crop. It has been demonstrated that the danger of loss from this source is very small under ordinary conditions of farming. Where, however, very large quantities of horse manure are applied, together with the nitrate, as happens occasionally in market gardening, this danger is quite real, and sometimes serious, for not only is there a destruction, under such conditions, of all of the nitrate applied, but also of the nitrate in the soil formed there by the nitrification of organic nitrogen.

Where ammonia nitrogen is applied, the proportion recovered in the crop is smaller than that recovered from nitrate. This is accounted for by the fact that the ammonia is nitrified in the soil—that is, changed into nitrate. This change from the ammonia to the nitrate form involves unavoidable losses of nitrogen, part of which may escape in gaseous form; hence the ammonia nitrogen is said to be less available than the nitrate nitrogen. The nitrogen in the organic combinations is subject to even greater losses. It must go through several processes of change, in the course of decay, before it reaches the ammonia form, and each of these may be accompanied by greater or smaller losses of nitrogen.

Comparison of availabilities.—It is customary to measure the value of the different forms of nitrogen by their availability—that is, by the proportion of nitrogen which they may be expected to yield to the crops within a reasonable length of time—for not only are there marked differences in the availability of nitrate, ammonia, and organic nitrogen, but also in the availability of the nitrogen of the different organic substances, as already indicated. An enormous amount of work has been devoted to the comparison of the availabilities of the nitrogen of the different substances under different conditions and with different crops, and tables have been prepared showing the relations thus observed. The comparative availabilities are established in these tables by taking the yield from the nitrate nitrogen at 100, and using this as a standard for measuring the yields from the other substances. It will be seen, therefore, that the actual availabilities are smaller than the comparative availabilities, since the return from the nitrate nitrogen never actually reaches 100 per cent. Furthermore, while practically all of the effect from the application of nitrate or ammonia nitrogen is obtained in the first season, the effect from manure nitrogen or other forms of organic nitrogen is often considerable in the second or even the third season—a fact which must not be overlooked in the study of availabilities. Basing his calculations on hundreds of such studies with a number of different crops, Wagner has prepared a table showing the comparative availability of the nitrogen of the various substances under average conditions. The values given by him are far from fixed, since changed conditions of soil, climate, etc., may modify them to a considerable extent. Nevertheless, they are a fair approximation to the actual relations as they exist in most soils.

The average availability of different nitrogenous substances.

Nitrate of soda	100
Sulphate of ammonia	83
Dried blood, horn meal, rape cake, and green plant substance	65
Bone meal, ground fish, azotine	53
Wool waste and stable manure	25
Leather meal	15

PHOSPHORIC ACID.

Sources and Forms.

Phosphoric acid is derived from materials called phosphates, in which it may exist in combination with lime, iron, or alumina as phosphate of lime, iron, or alumnia. Phosphate of lime, however, is the form most largely used as a source of phosphoric acid. Phosphoric acid occurs in fertilizers in three forms: (1) That soluble in water, and readily taken up by plants; (2) that slightly soluble in water, but still readily used by plants, also known as "reverted;" and (3) that very sparingly soluble in water, and consequently very slowly used by the plant.

To these should be added a fourth form, which occurs in the so-called Thomas slag or "odorless phosphate." It is practically insoluble in water, but dissolves in the presence of certain salts or of plant acids, and, therefore, becomes useful as a ready source of phosphoric acid when applied to the soil. This and the soluble and reverted are designated as "available" phosphoric acid. The very sparingly soluble phosphoric acid, while not directly available to plants, is readily affected by certain chemical changes in the soil. The gases and organic acids produced in the decay of vegetable substances greatly increase its solubility and cause it to serve as a source of available plant food. Where it is intimately associated with organic substances in animal bone, the rate of its transformation into available forms is hastened to a considerable extent. By treatment with strong mineral acids it is converted into soluble forms, and the resulting products are designated as acid phosphates, or superphosphates.

"Organic" Phosphates.

Various forms of bone.—Bone, in its various forms, is the only one of the so-called insoluble phosphates that is now largely used directly upon the soil, or without other change than is accomplished by mechanical action or grinding. The terms used to indicate the character of the bone have reference rather to its mechanical form than to the relative availability of the phosphoric acid contained in it. The terms "raw bone," "fine bone," "boiled and steamed bone," etc., are used to indicate methods of preparation, and, inasmuch as bone is a material which is useful largely in proportion to its rate of decay, its fineness of division has an important bearing upon availability. This is quite evident, since the finer the bone the greater the surface exposed to the action of those forces which cause decay or solution, and hence the greater the rate of availability of its constituents. In the process of boiling or steaming, the bone is not only made finer, but its physical character is changed in other respects. The particles,

whether fine or coarse, are made soft and crumbly rather than dense or hard; hence it is more likely to act quickly than if the same degree of fineness were obtained by simply grinding. The phosphoric acid in fine steamed bone may all become available in one or two years, while the coarser, fatty, raw bone sometimes resists complete decay for three or four years or even longer. Bone contains, besides, considerable amounts of nitrogen—a fact which should be remembered in its use, particularly where it is compared with other phosphatic materials which do not contain this element.

Pure raw bone contains on an average 22 per cent of phosphoric acid and 4 per cent of nitrogen. By steaming or boiling, a portion of the organic substance containing nitrogen is extracted, which has the effect of increasing the proportionate amount of phosphoric acid in the product. Commercial samples of steamed bone contain 20 to 25 per cent of phosphoric acid and 2 to 4 per cent of nitrogen, but may contain as much as 28 per cent of the former and as little as 1 per cent of the latter.

Other phosphates derived from bone—such as boneblack, bone ash, etc.—are but little used directly as sources of phosphoric acid; for, while they are derived from organic sources, the treatment which they have received, besides depriving them of their nitrogen, causes them to be a much less valuable source of phosphoric acid than the various forms of bone already discussed. In both cases the organic substances which are more subject to decay have been removed—in the case of boneblack by heating the bone in air-tight vessels, and in bone ash by burning in the open air.

Tankage.—The term "tankage" is applied to the dried and ground animal wastes from the large abattoirs and packing establishments. The material is thus designated because it is the residual product after the waste portions of the carcass are steamed under pressure in large tanks for the extraction of the fatty substances. The mode of its preparation necessarily involves wide variations in composition, both as to the content of nitrogen and of phosphoric acid. The tankage made from hogs is usually richer in phosphoric acid and poorer in nitrogen than the tankage made from neat cattle. The more strictly nitrogenous grades of tankage are classified as "crushed" tankage and "concentrated" tankage, the former in its different grades containing from 4 to 9 per cent of nitrogen and from 3 to 12 per cent of phosphoric acid. The latter is a high-grade product, and is derived from the evaporation of the tank water containing the nitrogenous substances extracted from the animal tissues. It contains as much as 10 to 13 per cent of nitrogen and very little phosphoric acid. The bone tankages, more akin to bone in their composition, are richer in phosphoric acid and poorer in nitrogen than those mentioned above. Those sold in the

market are classified into five grades, containing, respectively, 18 to 19, 16, 13.5, 9, and 7 per cent of phosphoric acid. The content of nitrogen increases as the content of phosphoric acid decreases. In general, it may be said that the agricultural value of the tankage depends, apart from its composition, also on its mechanical condition.

Mineral Phosphates.

Sources.—The mineral phosphates differ from what may be termed "organic phosphates," in that they contain no organic or animal matter, and that they are more compact and dense in their nature. The chief sources of these phosphates in the United States are the river and land phosphates of South Carolina, the "soft," "pebble," and "rock" or "bowlder" phosphates of Florida, the phosphate from the mines of Tennessee, and phosphatic slag,[a] a waste product from the manufacture of steel from phosphatic iron ores. With the exception of the last, which is not an abundant product in this country, these phosphates are not yet used to any considerable extent, even when very finely ground,[b] without previous treatment with acid. They are, however, the chief raw materials from which superphosphates are made.

Superphosphates.—Superphosphates, or soluble phosphates, are derived from the insoluble materials already described by first grinding to a powder and then mixing with sulphuric acid, whereby the phosphoric acid is changed from the insoluble to the soluble form. The soluble phosphoric acid thus obtained is a definite chemical compound, and identical in composition irrespective of the material from which it was derived. The term superphosphate is, therefore, applied to any material containing soluble phosphoric acid as its chief constituent. In superphosphates there is nearly always present, however, in addition to the soluble, the reverted form, which is probably quite as useful as the soluble form. The superphosphates made from boneblack and bone ash differ from the mineral superphosphates mainly in showing a higher content of "available" phosphoric acid, an average of 16 per cent, which is practically all soluble. Mineral superphosphates contain on the average 14 per cent of available, which may include from 1 to 3 per cent of reverted, besides more or less of the insoluble. Superphosphates made from animal bone differ from those made from the other materials mentioned, in containing nitrogen in addition to phosphoric acid. They are, however, sometimes called "ammoniated superphosphates," or "dissolved ammoniated bone."

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[a] Also known as "Thomas phosphate powder," "Thomas slag," and "odorless phosphate."

[b] Finely ground mineral phosphate, known as "floats," has been used to a limited extent in some localities.

The so-called " double superphosphates " are a highly concentrated phosphatic material, containing as much as 40 per cent of phosphoric acid, almost all of it soluble. They are prepared by dissolving phosphate rock or bone in sulphuric acid, which contains a large proportion of free phosphoric acid. Because of their concentration and comparative freedom from impurities, they are especially valuable under certain conditions. On the whole, the superphosphates prepared from boneblack and bone ash are more uniform in composition than those prepared from rock phosphates; on the other hand, those prepared from animal bone show even greater variations than the mineral superphosphates, chiefly because of the very variable composition of the raw materials and of the greater difficulty in dissolving them properly.

Principles governing use.—The use of phosphoric acid should be governed not alone by its origin, but also by conditions of soil, crop, and climate. It is well known that the soluble phosphoric acid when applied to the soil readily unites with certain compounds of lime, iron, or alumina, or that it may enter in combination also with certain organic substances; the phosphoric acid is then said to be " fixed "—that is, it passes from the water-soluble to the " reverted " or to the " insoluble " form. This property of the soluble phosphoric acid to become " fixed " in the soil, and largely within the surface portion, is of direct importance to the farmer, for any excess of soluble phosphoric acid is thereby prevented from escaping. The phosphoric acid differs in this respect from the most valuable nitrogen compounds in the soil (the nitrates), since only traces of it are found in the drainage water, whereas the nitrates are not held back, but are carried off in large amounts in the drains. In soils well provided with lime the soluble phosphoric acid is " fixed " largely as " reverted " lime phosphate, while in soils deficient in lime the soluble phosphoric acid becomes " fixed " by uniting with compounds of iron and alumina. From the practical standpoint this difference in the method of fixation is quite important, since the reverted lime phosphate may become available quite readily through the agencies of decay, while the phosphates of iron and alumina become available much less readily. It has been shown that soils to which superphosphates are applied year after year retain all but a small proportion of the phosphoric acid within the upper 9 inches of soil, and that of the phosphoric acid thus retained a third or more may be present in the reverted form. Light, sandy soils, poor in humus, do not as readily retain the soluble phosphoric acid; and, where they are very open and porous, the application of large quantities of superphosphate may involve losses of phosphoric acid. Their retentive power may be increased by liming, marling, or green manuring,

as well as by the application of animal manures. Because of their open character, they frequently give better returns from Thomas phosphate or bone meal. On the other hand, the application of superphosphates is found to yield good returns on heavier fine-grained soils, or on the lighter sandy and sandy loam soils in a good state of cultivation.

The insoluble phosphates may be made more quickly available by increasing the proportion of organic matter in the soil. It has been found that satisfactory returns may sometimes be secured from the application of ground phosphate rock, where the soil humus is undergoing rapid decay. Under conditions like these the purchase of large quantities of finely ground rock may prove a good investment in the maintenance of soil fertility. It should be remembered, nevertheless, that, in by far the greatest number of instances, a phosphate is only valuable in proportion to its content of soluble and reverted phosphoric acid; and, where the raw rock yields remunerative returns, it is due largely, apart from other influences, to its fine state of division.

POTASH.

Forms.—Potash may exist in a number of forms, though chiefly as chlorids, or muriates, in which case the potash is combined with chlorin, and as sulphates in which the potash is combined with sulphuric acid. With potash, however, the form does not exert so great an influence upon availability as it does in the case of nitrogen and phosphoric acid. All forms used in the fertilizer industry are freely soluble in water, and are believed to be nearly if not quite equally available as food. The form of the potash has, however, an important influence upon the quality of certain crops, which is due to the constituents with which the potash is associated rather than to the potash itself. For example, it has been demonstrated that the quality of tobacco, potatoes, and certain other crops is unfavorably influenced by the use of muriate of potash, while the same crops show a superior quality where materials free from chlorids are used as the source of potash.

Sources.—The chief sources of potash salts at the present time are the potash mines of north Germany, and the products of these mines, which are now readily obtainable in this country, are kainit, sylvinit, muriate of potash, high-grade sulphate of potash, and double sulphate of potash and magnesia, or double manure salts. The kainit and sylvinit are crude products of the mines, and contain, in addition to potash, a number of other salts, chiefly ordinary salt (sodium chlorid) and magnesium sulphate. The potash in kainit, though in the form of a sulphate, produces an effect quite similar to that derived from the use of muriate, because of the large quantities of chlorids mixed with

it. It contains on the average about 12½ per cent of actual potash. Sylvinit differs from kainit in containing a slightly higher per cent of potash, which exists both in the form of a sulphate and of a chlorid, and a lower content of the magnesia and other salts. The other potash products mentioned are manufactured from the crude forms, and are much more concentrated. The muriate and sulphate contain on the average about 50 per cent of actual potash. The chief impurity in the case of the muriate is common salt. The double sulphate of potash and magnesia contains about 26 per cent of actual potash, though much lower grades of this material are found.

Principles governing use.—Potash salts are used to best advantage on light, sandy soils, on humus soils, and also on calcareous soils. Clay soils and clay loams, on the other hand, respond much less frequently to applications of potassic fertilizers. On sandy soils the best results from the application of potash are secured only in the presence of sufficient lime. Without the latter, a considerable portion of the potash applied may be leached out from open, porous soils. On the other hand, heavy soils, or even the lighter soils, well provided with lime, hold on tenaciously to the potash which they receive. The potash which is thus "fixed" in the soil is retained mostly near the surface, although a considerable portion of it may pass into the subsoil, to be retained there. In heavy clay soils but a slight proportion passes into the deeper layers, whereas in the lighter sandy or sandy loam soils the zone of fixation is much greater. As in the case of the phosphoric acid, the potash that is thus fixed is retained in a more soluble form than that derived from the weathering of rock fragments in the soil, and hence possesses a greater value, as a source of potash, to crops. On soils rich in organic matter, as, for instance, reclaimed marshes or swamps, the application of potash is, as a rule, quite profitable. It has been found, however, that on soils of this character the use of large quantities of kainit, or of other potash salts rich in chlorids, injuriously affects the crops. The defect can be remedied by the generous use of lime—a procedure not always desirable, because of the too rapid oxidation of the organic matter—or by the use of potash in the form of sulphate. Occasionally the application of potash gives increased crop returns also on heavy soils, which still contain large stores of potash, but in a form not readily available to the crops. Certain crops, like potatoes, beets, mangels, etc., are particularly grateful for an abundant supply of available potash. It is best, however, especially in the case of potatoes and sugar beets, to apply the potash salts in the preceding fall, or at least some weeks before planting, lest the quality of the crop be unfavorably affected—in the former by a diminished content of starch, in the latter by the decreased proportion of sugar. Generous dressings of potash salts have also given gratifying returns with such crops as lupines, used as

green manures for the improvement of light soils. Where potash salts rich in chlorids are applied frequently, or in large amounts, the depletion of lime from the soil is hastened on account of the formation of lime chlorid, which is an extremely soluble salt, and is readily removed in the drainage waters. The formation of large quantities of lime chlorid in the soil is also objectionable, because of its poisonous action on growing plants, especially in acid soils. The poisonous action of lime chlorid under such conditions may be counteracted by the application of lime.

GRADE OF FERTILIZING MATERIALS.

Materials that do not show a wide variation in composition, and in which the constituents are practically uniform in their action, may be regarded as standard in the sense that they can be depended upon to furnish practically the same amount and form of the constituents wherever secured. For example, a ton of nitrate of soda or boneblack superphosphate (dissolved boneblack) will on the average furnish 320 pounds of nitrogen or of phosphoric acid, the nitrogen all in the form of a nitrate and the phosphoric acid practically all soluble. Hence nitrate of soda, sulphate of ammonia, dried blood, and superphosphates and potash salts are standard products, because they can be depended upon, both in respect to the content and form of their constituents.

On the other hand, the low-grade or nonstandard materials are not merely poorer in their total content of plant-food constituents, but also contain forms of the latter which are very variable in their availability. No exact value can be assigned, for instance, to ground bone, since this is a product quite variable in composition and in the availability of its nitrogen and phosphoric acid, owing to its origin, its mechanical condition, and the method of treatment to which it was subjected. Because of the differences thus introduced different samples of bone can not be expected to yield the same results, even though they be used under the same conditions of soil and climate. The same applies even more strongly to the various kinds of tankage. We note here wide differences in the proportion of nitrogen and of phosphoric acid, and differences as great or greater in the availability of these constituents. They can not be expected, therefore, to yield constant and uniform results under any given climatic conditions in the same degree characteristic of the standard high-grade products.

AGRICULTURAL VERSUS COMMERCIAL VALUE OF FERTILIZERS.

What determines agricultural value.—The agricultural value of any of the fertilizer constituents is measured by the value of the crop increase which its use may be expected to produce. Knowing the

average composition of, let us say wheat, we may easily calculate the agricultural value of any given quantity of plant food as tending to produce, under suitable conditions, a certain increase in the yield of grain. The agricultural value of plant food is not a fixed quantity. It is a variable factor, depending upon the availability of the constituent or constituents, as well as upon the value of the crop produced. The availability of any constituent is, in turn, dependent on its origin, its treatment, and on the conditions of soil and climate under which it is applied, while the value of the crop produced is affected by its character, by the distance from the point of consumption, and by the conditions of demand and supply. It is quite evident, for instance, that the agricultural value of a pound of soluble phosphoric acid is likely to be greater than that of a pound of insoluble phosphoric acid, when applied under the same conditions of soil and crop, since in the one case the constituent is in its most available form, while in the other it is but slightly available. Furthermore, the soluble phosphoric acid in question may exert its full effect and lead to a large increase in the yield of certain crops without leading at the same time to increased profits. In other words, the increase produced by the application of the fertilizer may possess a value smaller than the cost of the latter. On the other hand the same fertilizer when used in connection with a crop possessing a greater market value may prove highly profitable, since the monetary return secured from the crop increase is much greater than the cost of the fertilizer. Hence it should be remembered that slowly available materials can not be expected to give profitable returns, particularly upon crops with a short growing season, and that expensive materials can not yield returns that are as remunerative with crops of relatively low value as they are with crops of relatively high value.

Commercial values of fertilizers.—The agricultural value should not be confused with what is termed "commercial value" or cost in market. The latter is determined by market and trade conditions, as the cost of the crude materials, the methods of their subsequent treatment, etc. Since there is no strict relation between agricultural and commercial value, it frequently happens that a constituent in its most available form, and possessing under suitable conditions a high agricultural value, costs less in the market than the same constituent in forms less available and possessing a slighter agricultural value. It is clear, therefore, that the commercial value, that is, the cost of any fertilizer constituent, need not necessarily bear a direct relation to its agricultural value, that is, the power of producing a certain crop increase.

The computation of the commercial value of complete fertilizers may be illustrated by the following example:

Method of computing values of complete fertilizers.

Constituent.	Pounds per hundred.	Pounds per ton.	Value per pound of constituent.	Value of constituent per ton of fertilizer.
Nitrogen:			*Cents.*	
As nitrate	1	20	17.0	$3.40
As ammonia salts	1	20	17.5	3.50
As organic matter	1	20	18.5	3.70
Phosphoric acid:				
Soluble	8	160	4.5	7.20
Reverted	1	20	4.5	.90
Insoluble	1	20	2.0	.40
Potash:				
Muriate	5	100	4.25	4.25
Sulphate	5	100	5.0	5.00
Total value per ton				28.35

The first figure column shows the per cent (pounds per hundred) of the constituents contained in the fertilizer; the per cent multiplied by 20 gives the pounds per ton in the second column; the figures in the latter, multiplied by the schedule prices per pound in the third column, give the valuation per ton, as shown in the fourth column.

VARIATIONS IN THE COMPOSITION OF MANUFACTURED FERTILIZERS.

Nature and causes of variations.—All manufactured products or brands of fertilizers are made up of a mixture of the various kinds and forms of the fertilizing materials just described, and the differences that exist in the brands of different manufacturers are due both to differences in the character and to variations in the proportions of the materials used to form the different brands; that is, while all manufacturers must go to the sources of supply indicated, they may select either good or poor products and may vary the proportions of the different materials used.

The difference between a good brand of fertilizer and a poor one lies not so much in differences that may exist in the total amount of plant food contained as in the quality of the materials of which the two are made. For instance, in one brand the nitrogen may have been derived entirely from insoluble organic materials and the phosphoric acid from untreated phosphates rather than superphosphates; while in another the nitrogen may have been derived from the three sources of nitrogen, viz, nitrates, ammonia salts, and organic matter, and the phosphoric acid entirely from superphosphates. The total plant food contained in the first brand may be quite as great as it is in the other, yet the immediate results obtained from its use would be less satisfactory than those obtained from the one containing the more active forms of fertilizing constituents.

A fertilizer containing foreign substances, of themselves worthless as a source of plant food, is not necessarily adulterated. It may contain the full quantity of the fertilizer ingredients guaranteed, and the foreign substance in question may act only as a filler. On the other hand, a fertilizer may contain one or more of the plant food constituents in forms so inert, and so difficultly available, as to make them practically worthless as a source of the constituents in question. This would apply, for instance, to peat, which in a finely ground state is known to have been used as a source of nitrogen in mixed fertilizers. Because of its resistance to the agencies of decay, it possesses scarcely any value as a source of nitrogen, and hence its use under such conditions could justly be designated as adulteration.

What chemical analyses show.—The differences that exist between good and poor fertilizers are quite clearly shown by the chemical analyses made by the various experiment stations, provided the analysis is carried far enough to show both the amount and form of the nitrogen, phosphoric acid, and potash. For instance, an analysis which shows that a considerable proportion of the nitrogen exists as nitrates or as ammonia is positive evidence that good nitrogenous materials have been used; if it shows that the phosphoric acid is largely in a soluble form, the consumer knows that superphosphates have been used. On the other hand, if all the nitrogen is shown to be in the form of organic matter, and a large proportion of the phosphoric acid is found to be insoluble, it is evident that materials containing less active forms of plant food were used in the preparation of that fertilizer. In the next place, it is the quality and amount of plant food contained in a fertilizer which determines its value, rather that the relative proportion of the various constituents, though under certain well-known conditions the latter is of very considerable importance. Special crop brands are particularly useful only when the soil is already in a good state of fertility and not deficient in any plant-food constituent.

THE PURCHASE OF FERTILIZERS.

As a rule, farmers are inclined to purchase fertilizers on the ton basis without sufficient regard to the amount or form of the constituents contained in them. The direct value of a fertilizer is determined by the percentage of nitrogen, phosphoric acid, or potash which it contains; hence, the buying of a fertilizer is virtually the buying of one or more of these constituents. The more concentrated the material or the richer it is in plant food, the less will be the proportionate expense of handling the constituent desired.

HIGH-GRADE AND LOW-GRADE MIXTURES.

The following are illustrations of the methods by which brands may be made up, the differences that may exist in the content of

actual fertilizing constituents, and the causes of variation in ton prices:

Formula No. 1.

	Pounds.		Pounds.	P. ct.
Nitrate of soda	500,	furnishing nitrogen	80,	or 4
Boneblack superphosphate	1,100,	furnishing phosphoric acid	180,	or 9
Muriate of potash	400,	furnishing potash	200,	or 10
Total	2,000,	furnishing total plant food	460	

Formula No. 2.

	Pounds.		Pounds.	P. ct.
Nitrate of soda	250,	furnishing nitrogen	40,	or 2
Boneblack superphosphate	1,000,	furnishing phosphoric acid	160,	or 8
Muriate of potash	80,	furnishing potash	40,	or 2
Make-weight	670			
Total	2,000,	furnishing total plant food	240	

Formula No. 1 shows a high-grade product, both as to quality of plant food and concentration, while No. 2 is high grade only in quality. In the latter it is necessary to add what is called "make-weight," or a diluent, usually consisting of substances that are of no direct fertilizing value, in order to make up the weight to 1 ton.

High-grade mixtures can not be made from low-grade materials. Low-grade mixtures can not be made from high-grade materials without adding "make-weight." The advantages of high-grade products are concentration and high quality of plant food.[a]

It will be observed that formula No. 1 contains nearly twice as much plant food as No. 2; or, in other words, it will require the purchase of about 2 tons of a fertilizer made according to formula No. 2 to secure the same total amount of plant food as is contained in 1 ton of No. 1. Now, the material in No. 2, other than the actual plant food, possesses no direct fertilizing value; but the actual cost of the constituents is considerably increased, because the expenses of handling, bagging, shipping, and selling are just double what they would be for No. 1.

It has been shown by continued studies at the New Jersey Experiment Station that the charges of the manufacturers and dealers for mixing, bagging, shipping, and other expenses are, on the average, $7 per ton; also, that the average manufactured fertilizer contains about 300 pounds of actual fertilizing constituents per ton. A careful study of the fertilizer trade indicates that these conditions are also practically true for other States in which large quantities of commercial fertilizers are used.

[a] First Principles of Agriculture, E. B. Voorhees, p. 109.

Formula No. 1 would contain 460 pounds of actual available fertilizer constituents per ton—160 pounds, or over 50 per cent, more than is contained in the average manufactured brand; that is, a farmer purchasing a brand made up according to formula No. 1 would secure in 2 tons as much plant food as would be contained in 3 tons of the average manufactured brand. Assuming that the charges per pound of plant food and the expense charges are the same in each case, and also that the quality of plant food in the one is as good as in the other, the consumer would save $7 by purchasing 2 tons of the former instead of 3 tons of the latter.

Thus is shown the very great saving that may be effected in the purchase of fertilizers as viewed from the standpoint of concentration alone, or, in other words, the importance of a definite knowledge of what constitutes value in a fertilizer. This saving may be accomplished, too, without any detriment to the manufacturer, since the difference to him between making high-grade or low-grade goods, so far as concentration is concerned, is largely a matter of unskilled labor. The manufacturers are in the business to cater to the demands of the trade. If consumers are intelligent, high-grade rather than low-grade goods will be provided by the manufacturers. Furthermore, as already indicated, high grade from the standpoint of concentration means high grade in quality, for high-grade mixtures can not be made from low-grade products.

HOME-MIXED FERTILIZERS.

In many cases, too, it is desirable to purchase the unmixed fertilizing materials, either for use singly or for home mixing. Here, too, a great saving may be effected (1) in the cost per pound of the constituents, (2) in freight rates, and (3) in having the mixing performed by the ordinary labor of the farm at times when it does not interfere with regular outdoor work. The advantages to be derived from this method are, however, fully realized only when it is possible to purchase fertilizers in large quantities and for cash.

As an illustration of the saving that may be thus effected, it is but necessary to cite the experience of a farmers' organization in New Jersey, which now purchases annually some 800 to 1,000 tons of unmixed goods at a cost per pound of the ingredients from 25 to 40 per cent less than the average cost to those who buy the average mixture in small quantities "on time" from their local dealers.

It has been shown, too, by the studies of many of the experiment stations of both the East and South that the materials can be evenly mixed on the farm; besides, samples carefully taken show as good a mechanical condition as those made by the leading manufacturers.

This method of purchasing also possesses the further advantage of enabling the farmer to apply just the kind and form of ingredient

that he has found by experience or experiment to be best adapted to his soil and crop. Besides, he knows positively, particularly in case of the element nitrogen, whether it is in the form of nitrate, ammonia, or organic matter, and whether the organic nitrogen is contained in substances that are likely to decay quickly, as blood, cotton-seed meal, etc., or in such insoluble and slowly acting substances as ground leather, horn, etc. In mixtures the kind of organic nitrogenous substances used can not be definitely shown by a chemical analysis.

CONDITIONS UNDER WHICH FERTILIZERS MAY BE PROFITABLY USED.

With a more or less complete knowledge of the need of artificial supplies of fertilizer, the character, composition, and usefulness of the various materials, and the best method of purchase, the practical question arises, viz: Will it pay to use them?

PRINCIPLES GOVERNING PROFITABLE USE.

Many of our most successful farmers are, by their practice, answering this question in the affirmative. It is, however, not entirely a question of plant food with them, and one phase of it may be illustrated by the following typical case: Mr. A applies fertilizer; his crop is largely increased, and a reasonable profit is secured. Mr. B applies the same amount and kind under similar conditions of soil, and receives no benefit. The difference in results is due, not to the fertilizer, but to the farmer himself. In one case the natural agencies (sun, air, and water) were assisted and enabled to do their maximum work, because care was taken to make the conditions other than the supply of plant food as perfect as possible, while in the other they were prevented from exercising their full influence, because physical conditions of soil were imperfect, on account of careless plowing, seeding, cultivation, and cropping.

The production of a large crop—that is, the transformation of large amounts of plant food into plant substance—presupposes not only an abundance of all of the ingredients, but the absence of unfavorable influences, such as excessive moisture, low temperature, improper aeration, acidity, etc.

In other words, the profit from the use of fertilizers is measured to a large degree by the perfection of soil conditions which are entirely within the power of the farmer to control. The production possible from a definite amount of plant food can be secured only when the conditions are such as to permit its proper solution, distribution, and retention in the soil.

It has been demonstrated that it is entirely practicable and profitable under certain conditions to use as much as 1,000 to 1,200 pounds

of high-grade commercial fertilizers for top dressing grass lands. The successful practice in this case is, among other things, dependent upon the absence of too great a degree of acidity in the soil and the presence of a good stand of timothy and redtop; in other words, of a sufficient number of vigorous plants to utilize to the best advantage the food offered to them. It has also been demonstrated that the best returns from the use of fertilizers may be secured when proper attention is paid not only to the varying needs of the different crops but also to the varying needs of the different soils. Applications of fertilizer ingredients suitable both in amount and proportion for one soil may be ill advised and wasteful on another soil. It is therefore necessary in the rational use of fertilizers to study the needs of the crop as well as of the soil. On certain soils and under certain conditions of crop rotation it may be advisable to provide for a better circulation of soil fertility by the use of the more slowly available, and therefore cheaper, forms of nitrogen and of phosphoric acid. Thus, there may be conditions, as already indicated, where finely ground phosphate rock, when used on soils well supplied with rapidly decomposing organic matter, may serve as a more economical source of phosphorus than superphosphate.

The fact that fertilizers may now be easily secured and are easily applied has encouraged careless use rather than a thoughtful expenditure of perhaps an equivalent amount of money or energy in the proper preparation of the soil for them. Of course it does not follow that no returns are secured from plant food applied under unfavorable conditions, but it needs to be emphasized that full returns can not be obtained under such circumstances, either with or without fertilizers.

It should be the aim in the use of commercial fertilizers to supplement the plant food derived from the soil itself in such a manner as to make possible the most profitable returns. The farmer should be in a position to decide whether the increase produced by the application of any given fertilizer is sufficient to pay for the extra expenditure of labor and money. He will be in a better condition to decide correctly by remembering that the relation of the cost of the fertilizer to the value of the increased crop is a variable factor, depending, aside from the climatic conditions, upon the availability of the constituents, the character and composition of the crop, and upon the market value of the latter. It may happen, for instance, that the liberal application of certain nitrogenous materials to crops of a low market value may result in a maximum yield of plant substance, and yet fail to return a profit simply because the cost of the nitrogen applied is so great as to exceed the value of the increase secured by its application. On the other hand, a similar application of the same material to a crop possessing a high commercial value may, without being

as thoroughly utilized or without producing an increase proportionately as large, lead to much greater profits, mainly because the cost of the nitrogen, however considerable, is relatively small when compared with the money value of the crop increase secured from its use.

RESULTS WITH CERTAIN CROPS.

It has been shown by certain experiments with nitrate of soda on a number of different crops that, whereas the grain and forage crops, utilizing the nitrate as completely as did the market-garden crops in the same experiment, showed an increase not exceeding in any case a value of $14 per acre, that is, a money return at the rate of $8.50 per 100 pounds of nitrate used, the market-garden crops yielded an increase whose value amounted in the case of one crop to as much as $263 per acre, which was equivalent to a return of approximately $66 per 100 pounds. The striking difference in the returns may easily be accounted for by the fact that in the one instance the nitrate nitrogen was built into a bulky crop, consuming large quantities of plant food, and possessing a low market value—dry hay, bringing, say, $12 per ton, and two tons per acre being considered a good yield—while in the other it was built into a material possessing a high market value—succulent vegetables, bringing as much as hay per ton and the yield being five to ten times as great. It is evident, therefore, that these relations of the cost of fertilizer and of the value of the crop returns are exceedingly important, and deserve careful consideration in the purchase of plant-food constituents. It is for this reason that it is so difficult to secure a reasonable profit from the unsystematic use of fertilizers upon such staple products as wheat, corn, oats, cotton, and tobacco—crops quite exhaustive in their manurial requirements and possessing a relatively low value.

On the other hand, the growth of such crops as potatoes, tomatoes, sweet potatoes, forage crops for the dairy, and vegetable crops for the market or cannery by the use of high-priced plant food is more often attended with profit, because they are usually crops of high market value and are proportionately less exhaustive.

In the case of such market-garden crops as tomatoes, cabbage, turnips, beets, and others, earliness and quality are important considerations. To be highly remunerative they must be harvested early; in other words, they must be forced—that is, their growth hastened at a time of the year when the decomposition processes in the soil are proceeding but slowly; hence the value of such substances as nitrate of soda. The edible quality of these products is likewise dependent in great measure upon uniform and rapid growth, and for this reason a supply of plant food in reasonable excess of ordinary demands is

essential in order to counteract, so far as possible, the unfavorable conditions of season. This should not be construed to mean, however, that the crops of lower commercial value should be abandoned, but rather that our systems of practice shall be changed so as to include in the rotation some high-priced crop, to which shall be applied such an abundance of plant food as to insure a yield, limited only by the season and climate, which will under average conditions of soil and season return a profit besides leaving a residue of plant food for the cereals, grasses, or catch crops that follow. These, being capable of extracting their mineral food from relatively insoluble sources, will yield a large increase of crop without a direct outlay for fertilizers. Farming will thus be more successful, because profitable crops are secured, while fertility is at the same time increased.

KIND OF FERTILIZER TO USE.

The kind of fertilizer to be used should be determined (1) by its composition—that is, whether it shall be nitrogenous, phosphatic, or potassic in its character, and not by the name of the brand or of the manufacturer; and (2) by the form in which the fertilizer constituents exist in it—that is, by the extent of their availability. A proper understanding of these points requires that we shall consider briefly the various classes of farm crops, and their power of acquiring food.

In deciding upon the kind of manure to use, the character of the soil must, of course, be taken into account. Crops grown on soils poor in decaying vegetable matter (humus) are, as a rule, benefited by applications of nitrogenous manures, while those grown upon soils well supplied with this substance are more benefited by phosphates and potash. Upon heavy soils phosphates are likely to be more beneficial than nitrogen, while the reverse is the case of light dry soil. All sandy soils are, as a rule, deficient in potash, while clayey soils contain this element in larger quantities. (See p. 10.)

In this discussion the barest outlines have been drawn. There are many exceptions to the general rules. The farmer, with the general principles well in mind, must use his intelligence in applying them to his conditions.

The cereals and grasses.—The cereals (Indian corn excepted, see p. 34) and grasses are quite similar in their habits of growth, and may be regarded as a class distinguished by extensive root systems and long periods of growth, which enable them to extract the mineral food necessary from relatively insoluble sources, and because of their very rapid development of leaf and stem during a short season just before maturity are unable to make normal growth during this period without an abundance of nitrogen in immediately available forms.

This period usually precedes the time of rapid nitrification, hence on soils of good natural fertility the application of nitrogen at the right time and in the form of a nitrate results in a largely increased crop. The fact here stated has led certain eminent scientists to regard nitrogen as a dominant or ruling element for this class of plants, a conclusion which is in the main correct where the limitations are properly understood.

The leguminous crops.—Clover, peas, beans, vetches, etc., belonging to the class of plants known as legumes, should also be regarded as a distinct class. They possess powers of acquiring food which, so far as we know now, are not common to any other class of cultivated plants. They do not depend altogether upon soil sources for their nitrogen, but draw this element partly from the air, and they make almost ravenous use of the mineral constituents, particularly potash and lime. A knowledge of these facts is not only useful in indicating the kind of manures to be used upon them, viz, an abundance of the mineral constituents only, but suggests that the growth of these crops must result in the enrichment of soils in the expensive element, nitrogen, so essential for crops whose exclusive source of supply is the soil.[a]

Root and tuber crops.—These may also be regarded as a class which, because of their habits of growth, are as a rule unable to make ready use of the insoluble mineral constituents of the soil, and hence for full development require an abundance of all the fertilizing constituents in readily available forms. Of the three classes of fertilizing constituents, the nitrogen is especially useful for the slow-growing beets and mangels; phosphates are required in abundance for the turnip; and potatoes, both white and sweet, respond favorably to liberal dressings of potash. Thus, while the fertilizers should contain all three elements, certain of the crops, because of their peculiarities of growth, require certain of them in greater relative amounts and in immediately available forms.

The object of the growth, too, whether for the immature produce or for the fully developed plant, is a matter worthy of careful consideration. In other words, shall the fertilizing be of such a character as to stimulate and force an unnatural and artificial growth, or such as assists in the natural development of the plant? That the specific function of nitrogenous manures is to encourage and even force leaf development is a fact not disputed by the highest authority; hence their use in stimulating unusual growth is of the greatest importance in growing market-garden crops, in order that the tenderness and succulence, which is the measure of quality in most of those products, may be secured.

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[a] U. S. Dept. Agr., Farmers' Buls. 58, 240, and 245.

Orchard trees.—Fruit trees are slow-growing plants, and therefore do not need quick-acting fertilizers as a rule. They appropriate plant food very slowly, and highly soluble manures, such as nitrate of soda, are liable to be washed out of the soil without being utilized. For this reason the use of nitrate of soda is not advised, except where the growth of nursery stock is to be forced or where bearing trees exhibit a lack of luxuriance in foliage. The old and still common practice of fertilizing fruit trees every few years with slowly decomposing manures, such as barnyard manure, leather waste, horn refuse, wool waste, leaf mold, tobacco stems, etc., is thus seen to have more or less of a scientific basis. Frequently, however, it is desirable to stimulate the growth and fruitfulness of the trees, and for this purpose more active fertilizing materials than the above are needed. In selecting and mixing the latter, the fact that fruits are "potash feeders" should be taken into consideration.

Probably there is no better fertilizer for fruit trees than a mixture of muriate of potash and ground bone (1 part of the former to 1½ parts of the latter). A good practice is to apply this mixture to clover or some other leguminous crop which is turned under as a green manure, and in addition, where tobacco stems can be obtained cheaply, to apply these about the trees. Wood ashes or cotton-hull ashes may be substituted for muriate of potash, if these products can be obtained at reasonable prices.

Small fruits.—The fertilizer requirements of small fruits are similar to those of orchard fruits, but being as a rule more rapid growers they can utilize to advantage heavier applications of soluble fertilizing materials and do not derive the same benefit as orchard fruits from slowly decomposing manures.

IMPORTANCE OF SYSTEMATIC USE OF FERTILIZERS.

The suggestions already given lead to another of great importance, viz, that the use of fertilizers should be systematic. In order that this may be accomplished, a definite system of cropping should be adopted and a definite scheme of manuring worked out that shall meet the conditions of crop, season, and climate, and enable the farmer to utilize to the best advantage home and local supplies of manure. While it is impossible to give more than the merest outline of such methods, the following suggestions are offered:

In the first place, in nearly every State or even locality, some one system of cropping is better adapted to the conditions than another. It may be the "extensive system," which includes large areas and such crops as grain, cotton, tobacco, or sugar cane; or the "intensive system," with smaller areas and crops of quicker growth and higher value. For the former, a method of manuring should be adopted

which is not too expensive, but which provides for increased crops and gradual gain in fertility. It would be impracticable in extensive farming, for example, to attempt to increase the yield of a wheat crop from 12 to 30 bushels per acre by the addition of fertilizers only; for, as already pointed out, plant food is but one of the conditions of fertility, and if it were practicable from the standpoint of yield, it would be folly from the standpoint of profit.

FERTILIZERS IN A FOUR-YEAR ROTATION.

A study of the following common four-year rotation—Indian corn, potatoes, wheat, and hay—will illustrate what is meant by rational and systematic methods of manuring:

First year—the corn crop.—On soils of medium fertility spread the farm manure during fall and winter, and after the land is plowed apply broadcast and harrow in, or harrow first and then drill in, 400 pounds per acre of a mixture made up of 100 pounds each of (1) cotton-seed meal or ground fish, (2) ground bone, (3) acid phosphate, and (4) muriate of potash, or their equivalents in kind and form of other fertilizer constituents. This mixture would have approximately the following composition: Nitrogen, 2.5 per cent; phosphoric acid, 10 per cent, and potash, 12.5 per cent. If the land had not been previously manured, or if it is of a light, sandy character, the proportion of nitrogenous matter should be increased and the total application should be heavier, say from 600 to 800 pounds.

Corn makes its most rapid growth and development during the hot season, which is very favorable for rapid decay and consequent nitrification of organic substances in the soil. The nitrogenous manures, therefore, may be less in amount than for crops which develop rapidly earlier in the season, and for the same reason may consist of organic forms. The mineral constituents, particularly the phosphates, which the crop acquires less readily because of its comparatively short season of growth, are applied in such forms and in such amounts as to provide for a largely increased crop, even though the seasonal conditions are not perfect.

Second year—the potato crop.—For the potatoes, as a minimum application, 650 pounds per acre of the following mixture may be used:

Fertilizer for potatoes.

	Pounds.
Nitrate of soda	50
Cotton-seed meal, or dried ground fish, or meat tankage	150
Ground bone	100
Acid phosphate	200
Muriate or sulphate of potash	150

This mixture contains nitrogen 3 per cent, phosphoric acid 8 per cent, and potash 12 per cent. In this application we are guided by certain other well-defined principles, the chief of which are: The value of this crop is such that the farmer can afford a more expensive manuring. Since it grows and matures in a comparatively short time, we need to furnish a reasonable excess of plant food in order that the crop may be abundantly supplied even though unfavorable conditions occur. It is a crop which is particularly benefited by potash, and we must therefore provide that element in largest proportion; and as it is not an exhaustive crop, we may expect considerable increase in soil fertility due to the unused residue.

Third and fourth years—the wheat and hay crops.—After the potatoes are removed, the land, on account of the frequent cultivation of the potato crop, is in the fine mechanical condition essential for the rapid germination and early growth of the wheat. It is also well supplied with plant food because of the manure applied to the previous crops in excess of their needs. For the wheat, therefore, such home supplies of manure as are available may be applied after plowing, and well worked into the surface soil with the addition at time of seeding of 200 pounds per acre of dissolved bone, or a mixture of 100 pounds each of ground bone and acid phosphate. In spring, if the crop does not show a vigorous condition, sow broadcast 100 pounds per acre of nitrate of soda.

By this method the manuring is accomplished at a minimum expense, and the phosphates which are so essential for the proper development of the grain are provided, partly in an immediately available form, partly in a form that will gradually decompose and feed the crop at later stages of growth. The nitrogen is applied when the plant has greatest need for it, and in a form immediately available, while for potash the plant depends entirely upon the accumulated soil supplies. The hay crop which follows, if it consists of clover, will be able to make normal growth with added supplies of phosphoric acid and potash only, which may consist of a mixture of equal parts of acid phosphate and muriate of potash, at the minimum rate of 200 pounds per acre.

This method of fertilizing should not be changed from year to year, but followed in the succeeding rotation courses; and it will enable the farmer to secure an increased yield and improvement in soil at a minimum expense.

APPLICATION OF PRINCIPLES TO OTHER LINES OF FARMING.

The principles involved may also be applied in other lines of farming, modified by character of soil, climate, and kind of crop. In market gardening the amounts applied should be increased, and a

larger proportion of the more active forms should be used, because in this case quick-growing crops which belong to the high-value class are produced. For fruit trees, which feed slowly and continuously, the mineral elements, as already explained, should be applied in greater amounts, and may be derived from the cheaper and more slowly available forms.

SUMMARY.

(1) Commercial fertilizers are mainly valuable because they furnish the elements—nitrogen, phosphoric acid, and potash—which serve as food, not as stimulants.

(2) The kind of farming in the past and the demands for special products in the present make their use necessary in profitable farming.

(3) In order to use them profitably the farmer should know—

(*a*) That nitrogen, phosphoric acid, and potash are the essential manurial constituents.

(*b*) That the agricultural value of these constituents depends largely upon their chemical form.

(*c*) That these forms are contained in specific products of a well-defined character and composition, and may be purchased as such from dealers and manufacturers and may be mixed successfully on the farm.

(4) The agricultural value of a fertilizer bears no strict relation to the commercial value; the one is determined by soil, crop, and climatic conditions, the other by market and trade conditions only.

(5) The variations in the composition and value of manufactured fertilizers which contain the three essential constituents are due to variations in the character and in the proportion of the materials used.

(6) The ton basis alone is not a safe guide in the purchase of these commercial fertilizers. Low ton prices mean either low content of good forms of plant food or the use of poorer forms. Fertilizers, high grade both in quality and quantity of plant food, can not be purchased at a low price per ton.

(7) The best fertilizers can not exert their full effect on soils that are too dry or too wet, too compact, or too porous. They can furnish but one of the conditions of fertility.

(8) The kind and amount to use should be determined by the value of the crop grown and its power of acquiring food.

(9) A definite system or plan should be adopted in the use of fertilizers; "hit or miss" methods are seldom satisfactory, and frequently very expensive.

Composition of the principal commercial fertilizing materials.

Fertilizing material.	Nitrogen.	Phosphoric acid.			Potash.	Chlorin.
		Available.	Insoluble.	Total.		
Supplying nitrogen:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Nitrate of soda	15.5–16.0					
Sulphate of ammonia	19.0–20.5					
Dried blood (high grade)	12.0–14.0					
Dried blood (low grade)	10.0–11.0			3.0– 5.0		
Concentrated tankage	11.0–12.5			1.0– 2.0		
Tankage (bone)	5.0– 6.0			11.0–14.0		
Dried fish scrap	7.0– 9.0			6.0– 8.0		
Cotton-seed meal	6.5– 7.5			1.5– 2.0	2– 3.0	
Castor pomace	5.0– 6.0			1.0– 1.5	1– 1.5	
Supplying phosphoric acid:						
South Carolina rock phosphate			26–28	26.0–28.0		
South Carolina rock superphosphate (dissolved South Carolina rock phosphate)		12–15	1– 3	13.0–16.0		
Florida land rock phosphate			33–35	33.0–35.0		
Florida pebble phosphate			26–32	26.0–32.0		
Florida superphosphate (dissolved Florida phosphate)		14–16	1– 4	16.0–20.0		
Boneblack			32–36	32.0–36.0		
Boneblack superphosphate (dissolved boneblack)		15–17	1– 2	17.0–18.0		
Ground bone	2.5– 4.5	5– 8	15–17	20.0–25.0		
Steamed bone	1.5– 2.5	6– 9	16–20	22.0–29.0		
Dissolved bone	2.0– 3.0	13–15	2– 3	15.0–17.0		
Thomas slag[a]				11.4–23.0		
Supplying potash:						
Muriate of potash					48–52.0	45.0–48.0
Sulphate of potash (high grade)					48–52.0	.5– 1.5
Sulphate of potash and magnesia					26–30.0	1.5– 2.5
Kainit					12–12.5	30.0–32.0
Sylvinit					16–20.0	42.0–46.0
Cotton-hull ashes[b]				7.0– 9.0	20–30.0	
Wood ashes (unleached)[b]				1.0– 2.0	2– 8.0	
Wood ashes (leached)[b]				1.0– 1.5	1– 2.0	
Tobacco stems	2.0– 3.0			3.0– 5.0	5– 8.0	

[a] In good Thomas slag at least 80 per cent of the phosphoric acid should be soluble in ammonium citrate, i. e., available.

[b] Cotton-hull ashes contain about 10 per cent of lime; unleached wood ashes, 30 to 35 per cent; and leached wood ashes, 35 to 40 per cent.

FARMERS' BULLETINS.

The following is a list of the Farmers' Bulletins available for distribution, showing the number and title of each. Copies will be sent to any address on application to any Senator, Representative, or Delegate in Congress, or to the Secretary of Agriculture, Washington, D. C.

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